WATER CONTENT DETERMINATIONS FOR DRIED MARINE SEDIMENTS

by

John Christian Peterson

United States Naval Postgraduate School

THESIS

WATER CONTENT DETERMINATIONS FOR DRIED MARINE SEDIMENTS

by

John Christian Peterson

Thesis Advisor: R. J. Smith

March 1971

Approved for public release; distribution unlimited.

Water Content Determinations For Dried Marine Sediments

by

John Christian Peterson
Lieutenant, United States Navy
B.S., United States Naval Academy, 1963

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
March 1971

LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIF. 93940

ABSTRACT

A quantitative analysis of residual salts in dried marine sediments was accomplished by reconstituting the sediment with distilled water and measuring the salinity of the resulting solution. The information obtained from these measurements provided an excellent basis for predicting the water content of the original unaltered samples. With the original salinity of the interstitial water known the water contents computed from the salt content determinations were, for all practical purposes, as accurate as the original water contents.

TABLE OF CONTENTS

I. INTRODUCTION ---------- 7

A. OBJECTIVE ---------- 7

B. DISCUSSION ---------- 7

1. General ---------- 7

2. Shear Strength ---------- 8

3. Water Content ---------- 9

II. THEORETICAL APPROACH ---------- 13

A. GENERAL ---------- 13

B. SALINITY ---------- 13

1. Definition ---------- 13

2. Determination of Salinity ---------- 15

C. DETERMINATION OF WATER CONTENT ---------- 15

III. EXPERIMENTAL PROCEDURE ---------- 18

A. PREPARATION OF SAMPLE ---------- 18

B. DESCRIPTION OF EQUIPMENT ---------- 19

1. Conductivity Cell ---------- 19

2. Conductivity Bridge ---------- 20

3. Constant Temperature Bath ---------- 22

C. DETERMINATION OF CELL CONSTANT ---------- 23

D. DETERMINATION OF SPECIFIC CONDUCTIVITY-SALINITY RELATIONSHIPS ---------- 25

E. TESTING ---------- 27

IV. PRESENTATION OF DATA ---------- 28

A. SOURCE OF DATA ---------- 28

B. DISCUSSION OF RESULTS ---------- 35

1. General ---------- 35

2. Sources of Error ---------- 48

V. CONCLUSIONS ---------- 51

APPENDIX A ---------- 52

BIBLIOGRAPHY ---------- 61

INITIAL DISTRIBUTION LIST ---------- 64

FORM DD 1473 ---------- 65

LIST OF TABLES

Table

I Summary of Test Results for Monterey Bay Samples ---------- 29

II Summary of Test Results for Core PB-5 ---------- 31

III Summary of Test Results for Core SCNI 32 ---------- 32

IV Summary of Test Results for Core SCNI 33 ---------- 33

V Summary of Test Results for Core SCNI 37 ---------- 34

LIST OF TABLES

Table

I Summary of Test Results for Monterey Bay Samples ---------- 29

II Summary of Test Results for Core PB-5 ---------- 31

III Summary of Test Results for Core SCNI 32 ---------- 32

IV Summary of Test Results for Core SCNI 33 ---------- 33

V Summary of Test Results for Core SCNI 37 ---------- 34

LIST OF ILLUSTRATIONS

Figure

1 Conductivity Cell ---------- 20

2 Drying Oven ---------- 21

3 Sample Preparation ---------- 21

4 Block Diagram of Conductivity Bridge ---------- 22

5 Arrangement of Equipment ---------- 24

6 Conductivity Cell and Bridge ---------- 24

7 Salinity versus Specific Conductance ---------- 26

8 Santa Barbara Channel Core Locations ---------- 30

9 Water Content versus Depth in Core PB-5 ---------- 36

10 Water Content versus Depth in Core SCNI 32 ---------- 37

11 Water Content versus Depth in Core SCNI 33 ---------- 38

12 Water Content versus Depth in Core SCNI 37 ---------- 39

13 Error versus $\ln^{-1}$ (depth in core) ---------- 40

14 Improved Water Content versus Original Water Content ---------- 42

15 Salinity versus Depth in Core PB-5 ---------- 44

16 Salinity versus Depth in Core SCNI 32 ---------- 45

17 Salinity versus Depth in Core SCNI 33 ---------- 46

18 Salinity versus Depth in Core SCNI 37 ---------- 47

I. INTRODUCTION

A. OBJECTIVE

The objective of this investigation was to develop a simple means of determining the original water contents of dried and partially dried samples of ocean bottom sediments. Such a procedure should be applicable to all types of marine sediments and independent of the manner of sampling, handling, and storing. To make this objective practical the measurement techniques and required equipment should be readily available to most oceanographic and soil testing laboratories. The method developed should give reproducible results which compare favorably with those obtained by the current standard soils testing procedures used to determine the water contents of the original unaltered samples.

B. DISCUSSION

1. General

Oceanographic institutions and agencies throughout the world maintain cores and samples of marine sediments stored in various ways and subjected to non-standardized environmental conditions. These samples usually alter with time to such a degree that their present physical properties have no apparent relationship to their original *in situ* values. In some cases these cores and samples often represent the only information available about a particular area of the ocean bottom that may be of interest. In their generally dehydrated condition much of this information is distorted and, in some cases, totally lost. When the cost and time involved in

procuring these cores are considered, their value becomes significant and any effort toward extrapolating their original properties becomes justifiable.

2. Shear Strength

Of all the engineering properties of marine sediments that are considered, its shear strength appears to be most critical as it can be directly related to bearing capacity (Terzaghi, 1943) and, hence the bottom supporting ability. The shear strength naturally increases significantly as the sediment dries. This limits acceptable results as to the character of the bottom to a short period after the core has been taken, with this time depending on the interim storage conditions. This variation indicates, as noted by Richards (1962) and many others, that shear strength has an inverse relationship to water content. The exact degree and significance of this relationship have been the subjects of several detailed investigations.

Hoag (1970) devotes considerable effort to this area in attempting to establish an empirical formula that would relate shear strength to the index properties that could be obtained from a deep ocean core long after it had been removed from its in situ conditions. The index properties selected were; depth in core, liquid limit, plastic limit and the original water content. Using these parameters and the shear strengths previously determined in 701 samples of marine sediments, he developed by regression analysis the following equation which best explains the variation of shear strength:

$$\mathrm{Log}_{10}(s) = 1.866 + 0.0023\,(LL) - 0.597(1/D^{.3}) - 0.00454(w) + 0.00672\,(PL) \qquad (1)$$

s = Shear Strength (gm/cm^2)

LL = Liquid Limit (%)

D = Depth in core (cm)

w = Original water content (%)

PL = Plastic limit (%)

From this equation it is expected that the computed shear strength would be within $\pm$ 40 gm/cm^2 of the original shear strength 95% of the time. Water content and grain diameter were used in a similar analysis on a much more restricted sampling by Trask and Rolston (1950). For sediments with mean grain diameters of less than 32 microns the average computed shear strength was reported to be within 5% of that observed. The equation used was:

$$\mathrm{Log}_{10}(s) = \frac{7.5 - 3w - 4\ \mathrm{Log}_{10} D_{50}}{1.8 - \mathrm{Log}_{10} D_{50}} \qquad (2)$$

s = Shear Strength (PSF)

w = Water Content (%)

D_{50} = Median grain diameter (microns)

It is to be noted that the 400 samples used for the above development all came from the San Francisco Bay area and were all of the same basic mineralogical components.

In the similar work of Holmes and Goodell (1964) and Morelock (1969) the water content was also noted as playing a significant part in the shear strength determination. Richards and Keller (1962) indicate that the in-situ values of water content alone may eventually be sufficient to permit an estimate of shear strength.

3. Water Content

The most common method of obtaining the water content of a sediment is to weigh a portion of the wet material, dry it in an oven, and then re-weigh to obtain the dry weight. The difference in the two weights is considered as the weight of water originally in the sample. The assumption is made here that all the water, and only water, has been removed from the sample by the drying process. Argillaceous sediments have a tendency to adsorb and retain considerable quantities of water. Nutting (1927) reports that the adsorbed film of water in quartz sand is readily removed at 800°C yet approximately half remains at 250°C. Clay minerals presumably contain a considerable percentage of adsorbed water even after heating to 300-400° C. Ignition to temperatures sufficient to remove all of this water risks loss of water of crystallization from some of the component minerals, and oxidation or other chemical changes in others. (Hedberg 1936) Although the generally accepted temperature for drying soils is 110° C (Lambe 1951), it was concluded by King (1969) that except for very organic sediments temperatures up to 150° C were acceptable and permitted a decreased in drying time.

Sediment samples must be weighed as soon as possible after obtaining to minimize the effects of air drying. The sample is placed in an oven with a controlled temperature and dried until it reaches a constant weight, normally 3 to 12 hours depending upon the drying temperature and the type and quantity of sample present. It is preferable to cool the sample to room temperature first in a dessicator prior to the dry weighing. The final weight of the sample is assumed to be the weight of the solids fraction, and when subtracted from the

original weight yields the weight of water originally present.

$$W_T = W_S + W_W \tag{3}$$

W_T = Total Weight

W_S = Weight of Solids

W_W = Weight of water

The method used in the soil mechanics field for determining water content is the dry weight basis.

$$w = \frac{W_W}{W_S} \times 100 \tag{4}$$

w = water content, dry weight basis (%)

The water content on the dry basis is expressed as a percent and is commonly referred to solely as the water content or moisture content. (Hough 1969) Such a calculation does not however, take into account the weight of the salts remaining in marine samples after the water has been removed by evaporation. For marine sediments with low water contents this perhaps represents an insignificant error; however, for a sample with a water content of 200% and interstitial water of salinity 35‰ the true water content when the weight of salts is considered is increased to 214%. To use a more extreme example, a water content of 670% (Emery 1960) would be recomputed to 870%, with almost one quarter of the dry weight of the sample represented by salt. It is therefore evident that when comparing high water contents with other parameters, such as shear strength, the consideration of the residual salts significantly alters the results.

It can be concluded from the above that water content plays a significant role in an empirical equation for shear strength. Most of the other index properties used in the developments of the various equations can be determined after the sample has dried. [An exception would be the liquid limit. (Hoag 1970)] The need, then, of a method for determining water content from dried sediments becomes evident. Development of such a procedure would mean that current and future relationships for shear strength could be applied to the cores and samples now in storage to yield this heretofore unavailable parameter.

II. THEORETICAL APPROACH

A. GENERAL

The initial step in the determination of the original water content of dessicated cores of marine sediments involves their analysis for select constituents. Samples which have dried by evaporation contain a portion comprised of the salts originally dissolved in the interstitial water. The quantities of these salts are directly related to both the original water content of the sediment and the in-situ salinity of the interstitial water. Therefore, by measuring the amounts of salts in a known quantity of sediment, and by knowing the salinity of the interstitial water, the original water content can be determined.

A quantatative analysis of the salts in these sediments may be accomplished by redissolving them in a known quantity of distilled water and then measuring the salinity of the resulting solution. To more clearly understand this method it is best to discuss some of the parameters involved.

B. SALINITY

1. Definition

Salinity is one of the most commonly measured characteristics of ocean water. Salinities are frequently used by oceanographers to tag water masses and to distinguish one mass from another. Originally salinity was defined as the weight of salts dissolved in one kilogram of sea-water. Unfortunately, it is rather difficult to measure this definite quantity since, when sea-water is evaporated to dryness and

heated to high temperatures to remove the last traces of water, some hydrogen chloride, carbon dioxide and a small amount of hydrogen bromide are also lost. (Defant 1961) This loss is not easily compensated for and until recently salinity was defined as the total amount of solid material in grams contained in one kilogram of sea-water when all the bromine and iodine have been replaced by the equivalent amount of chlorine, all carbonate converted to oxide and all organic matter has been completely oxidized. With the development of precise methods for measuring the electrical conductivity of sea-water it became possible to adopt a new definition of salinity based on conductivity. (Wooster 1969)

$$S = -0.08996 + 28.29720\, R_{15} + 12.80832\, R_{15}^2 - 10.67869\, R_{15}^3 + 5.98624\, R_{15}^4 - 1.32311\, R_{15}^5 \qquad (5)$$

S = salinity (o/oo)

R_{15} = Conductivity ratio @ 15^0 C

Salinity is expressed as grams per kilogram or parts per thousand and the typical symbol used is S o/oo . The conductivity ratio, R_t, is the ratio of the specific conductance of a water sample to that of water having a salinity of exactly 35 o/oo , both samples being at the same temperature and under a pressure of one standard atmosphere.

Although the total variation of salinity is great when one considers all ocean areas the variation in a column of sea water or in a localized area is generally much less than one part per thousand and hence the need for the more accurate definitions for salinity. For this type of

study, however, small variations in salinity have an insignificant effect on the end result and all of the above definitions of salinity can be considered applicable.

2. Determination of Salinity

The classical method of determining salinity is by chemical titration. Detailed steps of this procedure can be found in Strickland and Parsons (1965). The titration method is difficult to use with some solutions since the end point in titration is determined by the appearance of a particular color which will be hidden by the solution itself if it is naturally clouded or colored.

Several indirect methods are used that measure parameters which can be related to salinity. An example of this is the conductivity ratio shown in equation (5). Although this equation will yield salinities, it is not very easy to apply without the aid of a computer and the accuracy is greater than that required for this type of study.

A simpler means of determining salinity is to use a common conductivity cell, which consists of two electrodes in a glass container rigged so that the conductivity of the electrical path between the two electrodes can be measured by a device such as a wheatstone bridge. This method was selected for the salinity measurements in this study and will be described in greater detail in a subsequent section.

C. DETERMINATION OF WATER CONTENT

With the salinity of a solution known it is possible to determine the weight of salt in that solution by:

$$W_{salt} = \frac{S_s}{1000} \times W_L \qquad (6)$$

W_{salt} = Weight of salt

W_L = Weight of solution

S_s = Salinity of Solution (o/oo)

In the situation where distilled water is added to a sample of dried sediment equation (6) must be modified.

$$W_L = W_A + W_{salt} \tag{7}$$

W_A = Weight of water added

Combining equations (6) and (7):

$$W_{salt} = \frac{S_s}{1000} (W_A + W_{salt})$$

$$W_{salt} = \frac{S_s}{1000-S_s} \times W_A \tag{8}$$

As noted previously this salt was left behind by the evaporation of sea-water. If the salinity of that water is known or assumed then, with a development similar to that for equation (8), the weight of water originally in the sample can be found by:

$$W_W = W_{salt} \times \frac{1000-S_o}{S_o} \tag{9}$$

W_W = Weight of original interstitial water

S_o = Salinity of interstitial water (o/oo)

With the already known weight of solids (W_S) and the computed weight of water (W_W) the water content can be calculated from equation (4)

$$W_c = \frac{W_W}{W_S} \times 100 \qquad (4)$$

W_c = computer water content (%)

By combining equation (4), (8) and (9) it is possible to determine the computed water content in one step:

$$w_c = \frac{1000-S_o}{1000-S_x} \times \frac{S_s}{S_o} \times \frac{W_A}{W_S} \times 100 \qquad (10)$$

The percent error when compared to the original water content determined by the method described earlier was found by:

$$E = \frac{w_c - w_o}{w_o} \times 100 \qquad (11)$$

E = error (%)

w_o = original water content (%)

III. EXPERIMENTAL PROCEDURE

A. PREPARATION OF SAMPLE

Preparation for analysis of salt content required drying each sample in an oven for 24 hours at a controlled temperature of 110° C. Upon removal from the oven it was placed in a dessicator and allowed to equalize to room temperature.

Samples were then ground to a fine powder with a motar and pestle. A rubber tipped pestle was found unsatisfactory for this purpose in that the dried sediments proved difficult to break up. Ten grams of the resulting powder were placed in a 250 milliliter (ml) flask, and to this was added 200 grams of distilled water. As long as accurate weights are recorded, it was not necessary to hold strictly to these proportions. A magnetic stirrer was used to mix the solution for a minimum of two hours. The stirrer also acted as a small grinder, breaking up the small remaining lumps of clay and putting all the salts into solution. The temperature of the solution was not controlled during this period; however, it was observed that it did not rise significantly above the ambient level and the flasks were tightly stoppered to minimize evaporation.

After the solution was thoroughly mixed it was allowed to settle for several minutes and then all but the heavier sediments in the bottom of the flask were filtered into a stopperable bottle through a #1 filter. It usually required about 10 minutes for 200 ml of the solution to pass through the filter. The color of the solution varied from sample to sample, but generally was a shade of amber with

very little visible suspended solid. The bottle was then stoppered and placed in a 25° C constant temperature bath until ready for testing.

B. DESCRIPTION OF EQUIPMENT

1. Conductivity Cell

Conductivity is the ability of a substance to pass electricity. It is the reciprocal of resistance and expressed in mhos or $ohms^{-1}$. The method chosen for determining conductivity in this study was to use a conductivity cell and a wheatstone or conductivity bridge.

Conductivity cells can be obtained commercially and vary in size and type depending on the concentration and volume of substance they are designed to measure. The conductivities of the filtered solutions described above were measured with a conductivity cell constructed of pyrex glass and having two platinum electrodes plated with platinum oxide or platinum black. The electrodes extended through the walls of the cell into arms partially filled with mercury. (Figure 1) Connections were made to a conductivity bridge by immersing the ends of the connecting wires into the mercury.

Prior to making any measurements with the cell the previous coating of platinum black was removed from the electrodes by partially filling the cell with a solution consisting of equal volumes of concentrated nitric and hydrochloric acids and connecting the cell to two 1-1/2 volt dry cells in series. The current was regulated with a rheostat so that a small amount of gas could be seen to evolve. The current was reversed every 10 to 15 seconds by alternating poles of the battery to ensure even cleaning. Once the cell electrodes

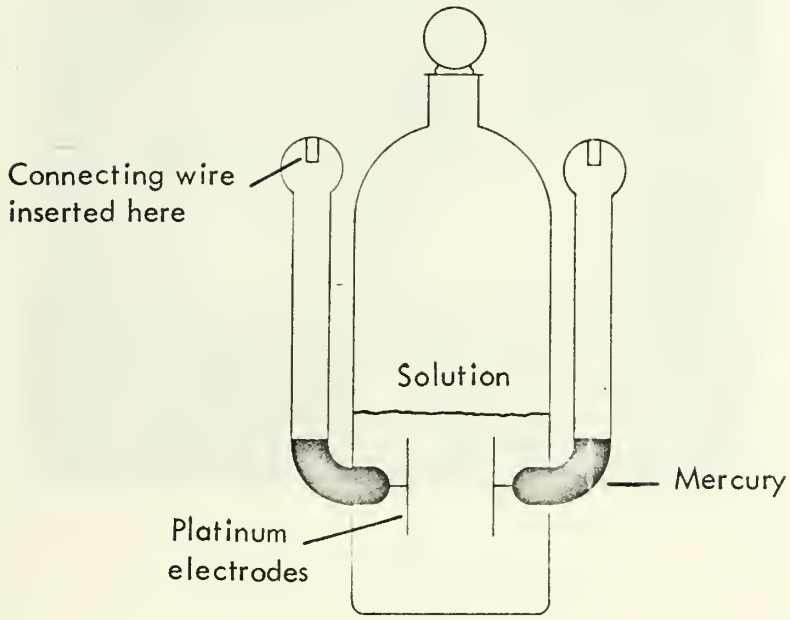

Figure 1. Conductivity Cell

were clean they were washed thoroughly with distilled water. Replating was done by following the same procedure using a commercially available platinizing solution in place of the acid. This solution is prepared from 3 grams of platinic chloride and .02 grams of lead acetate dissolved in 100 grams of distilled water. (Daniels et al. 1949) Once an even coat of platinum black had been deposited on both electrodes, the cell was thoroughly washed with distilled water. When the cell was not in use it was filled with distilled water.

2. Conductivity Bridge

The bridge used in this study was the Barnstead PM-70CB precision resistance/conductance bridge. It is a high sensitivity, high accuracy device using solid state components and integrated

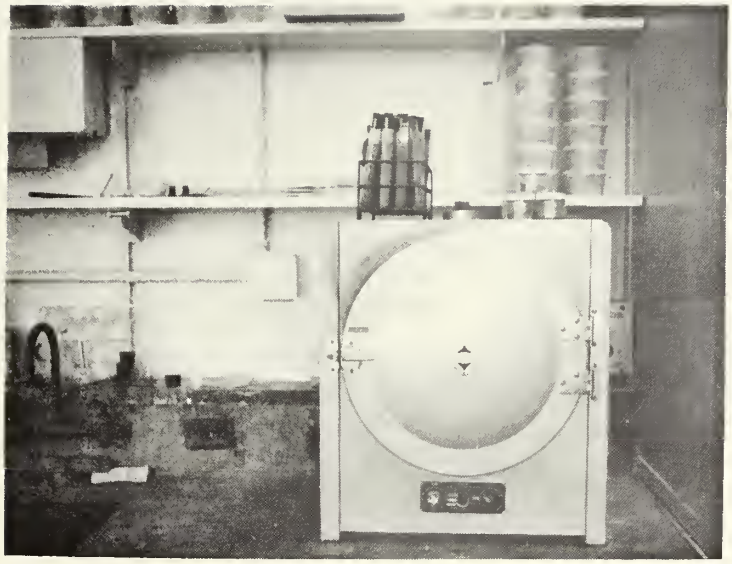

Figure 2. Drying Oven

Figure 3. Sample preparation

circuits. The unit uses an independent power supply consisting of two long life 4.2V mercury batteries. The circuit includes a square wave generator, a bridge, a high gain amplifier, and a detector.

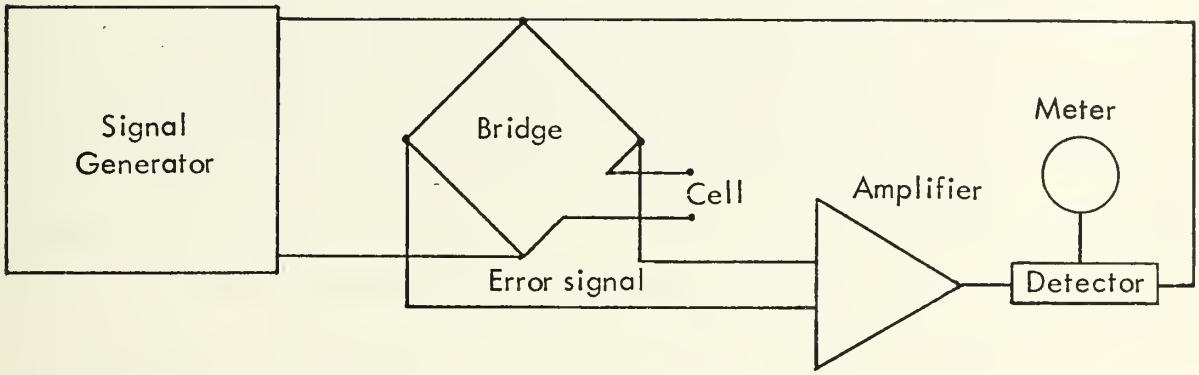

Figure 4. Block diagram of Conductivity bridge

The square wave generator supplies a signal of 400 hz to the bridge. The unknown conductance of the solution in the conductivity cell forms one arm of the bridge. The bridge error signal is fed to the amplifier and then to the meter circuit. The detector circuit shuts off the meter during the period of capacitive transient in the error signal and therefore the meter sees only the resistive component.

3. Constant Temperature Bath

The conductivity of a solution is not only dependent on the salinity of the solution but also the temperature. Therefore, in order to convert conductivity measurements to salinities it is necessary to either correct the readings for the temperature variations or take all readings at the same temperature. There are temperature conversion relationships (Weyl 1964) but for most work they

are complicated and difficult to use. A solution can be maintained at a constant temperature quite simply by immersing the conductivity cell containing the solution in a constant temperature bath. For this study, the constant temperature bath consisted of a 150 gallon tank filled with distilled water and a heating coil controlled by a micro-set thermoregulator. The thermoregulator responded to a temperature change of $\pm .01^{\circ}$ C, and with the aid of two electric circulators, was able to maintain the water temperature at $25^{\circ} \pm .05^{\circ}$ C throughout the tank. This temperature was chosen since it is one at which many studies are done today and also it was above ambient temperature and therefore no cooling coils were required.

C. DETERMINATION OF CELL CONSTANT

By use of the components described above, the reading obtained from the conductivity bridge yields the conductance of the solution in the cell. This conductance is related to both the nature of the solution in the cell and the area and separation of the cell electrodes. (Cole & Coles 1964) This relationship can be expressed by:

$$K = G\frac{d}{A} \tag{12}$$

K = Specific conductance (mho/cm)

G = Conductance (mhos)

d = Spacing between electrodes (cm)

A = Cross section area of electrode (cm^2)

The ratio d/A is known as the cell constant and is assumed invarient for a particular cell. This constant could vary with improper handling or with temperature change. Careful handling would preclude

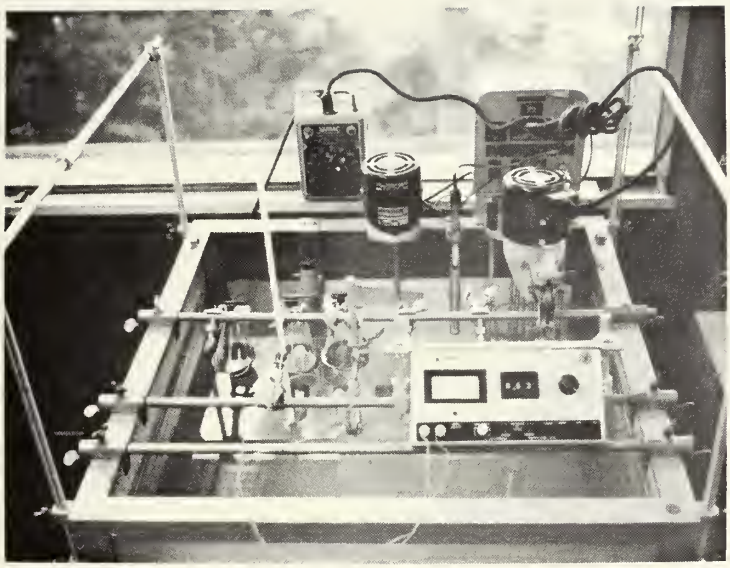

Figure 5. Arrangement of equipment

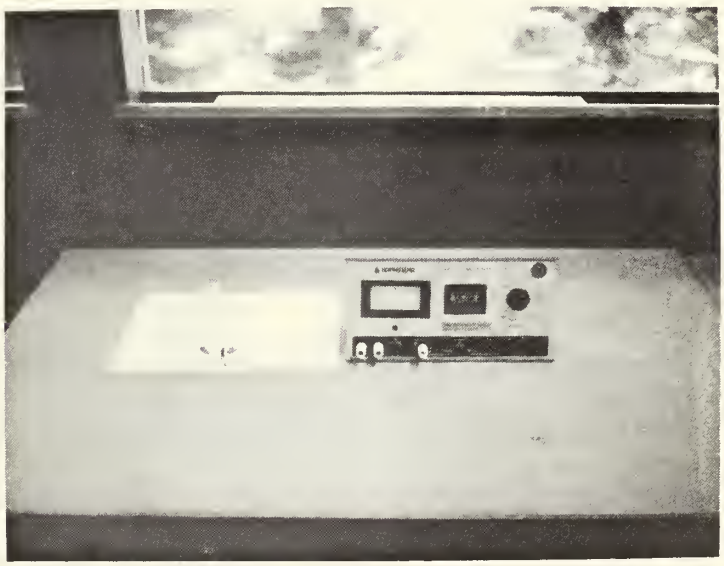

Figure 6. Conductivity cell and bridge

the former and Malmberg (1964) suggests that cell constants vary less than 0.1 percent with extreme temperature changes. To further minimize the possibility of a variation, the cell constant was determined and all unknown solutions measured at a constant temperature of 25° C.

Determination of the dimensions required to obtain the cell constant are difficult to accurately measure. Using a solution with a known specific conductance and measuring the conductance, the cell constant, however, can be found by:

$$k = \frac{K}{G} \tag{13}$$

$$k = \text{cell constant } (cm^{-1})$$

A solution of 0.1 normal potassium chloride was used to obtain the constant for the cell employed in this study. This solution had a specific conductance of 0.01288 mhos/cm at 25° C. (Handbook of Chemistry and Physics 1964), and the resulting constant was determined to be 0.208 cm^{-1}.

D. DETERMINATION OF SPECIFIC CONDUCTIVITY-SALINITY RELATIONSHIP

It was estimated that the solutions involved would have salinities from 0.5 °/oo to 6.0 °/oo . Very little past work exists to give data to establish a specific conductance-salinity relationship in this range. It was therefore decided to determine this relationship by measuring the conductances of a number of samples of known salinity made by diluting standard sea-water. A plot of salinity versus specific conductance was developed from these results. (Figure 7) Comparing this with points obtained from a linear interpolation of Table II,

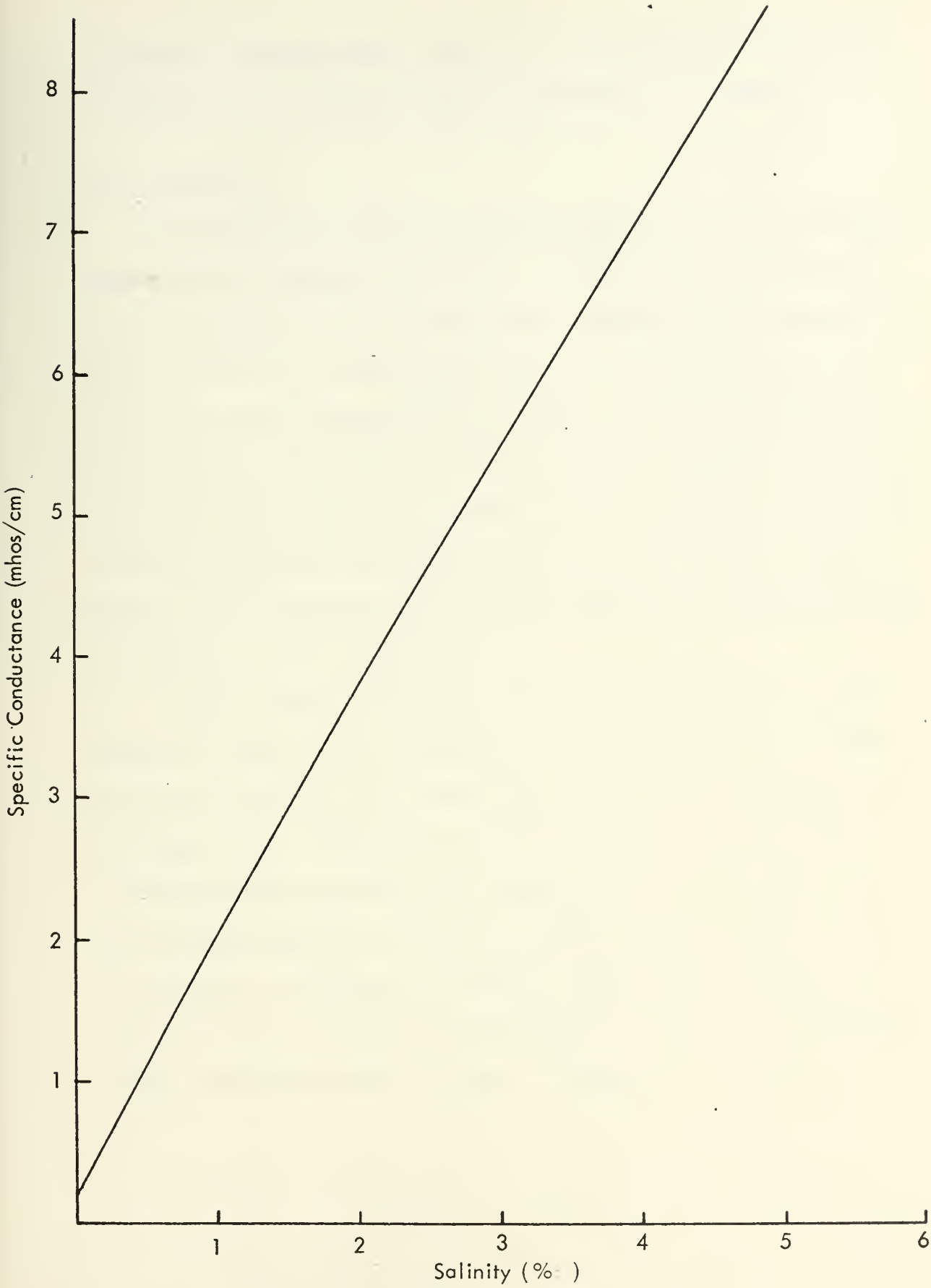

Figure 7. Salinity versus Specific Conductance

Handbook of Oceanographic Tables (U. S. Navy 1966) and the work of Thomas, et. al. (1934) showed a very close correlation.

E. TESTING

The conductivity of each sample was measured at 25° C at least three times. Between each test the cell was rinsed several times with distilled water to remove any film that might have developed on the electrodes, for a significant reduction in conductivity was apparent when this precaution was not taken. The cell was filled to a level of one quarter inch above the top of the electrode for each test. Even with these standard procedures there were still some variations between the measured conductivities of the same solution. Most of these could be minimized if five to ten minutes were allowed to enable the system to reach equilibrium.

Because of the cell design, it was difficult to prevent a small amount of water from accumulating in the arms of the cell. When mixed with the mercury in these arms a white film developed on the electrode wires. When this happened the measurements became extremely erratic and the cell arms had to be cleaned. This was done by removing the mercury and filling the arms with the same acid solution used earlier to clean the plates. After allowing the acid to soak for 10 minutes it was removed and the arms thoroughly rinsed with distilled water, dried, and clean mercury added.

IV. PRESENTATION OF DATA

A. SOURCE OF DATA

The first samples of marine sediments subjected to this testing were obtained with a Smith-MacEntyre grab-type bottom sampler from the southern end of Monterey Bay. These samples had some sand content and are assumed to be representative of at least the upper six inches of the sea floor in that area. A sample of the bottom water was obtained at the same time. Every attempt was made to minimize the errors introduced in the handling process.

A salinity analysis was made on the bottom water and several samples of the sediment were analyzed for water content using the normal procedure as outlined previously. This testing was completed within 24 hours of the time that the samples were taken. These samples were then tested for salt content by the method utilizing the conductivity cell and their water contents were again determined. The entire portion of the sample used for each original water content determination was also used for the corresponding computer water content analysis to ensure that if there was an uneven distribution of residual salts throughout the sediment it would be averaged and the error minimized when the sample was ground and prepared for testing. A comparison of the results obtained by the two methods is shown in Table 1.

The remainder of the samples investigated in this work were secured from the Naval Civil Engineering Laboratory (NCEL) in Port Hueneme, California. These samples were taken from cores

Sample #	Original Water Content %	Computed Water Content %	Error %
1	44.7	45.4	1.5
2	41.3	41.5	0.7
3	41.7	41.2	-1.2
4	39.1	39.5	1.0
5	37.4	37.3	-0.3

Salinity of bottom water - 33.9 $^{o}/oo$

Table I

Comparison of Original and Computer Water Contents

obtained in an area five miles north of Santa Cruz Island in the Santa Barbara Channel. (Figure 8) The cores were stored upright in the corer plastic liners with the ends capped and taped with less than a month of storage time elapsing before they were tested. The cores were prepared by dividing them into three inch intervals. The soil testing laboratory at NCEL then conducted standard soil tests on each interval (Appendix A) and the unused portion was then stored in a covered, non-airtight, plastic container.

By the time these samples were obtained for further testing at the U. S. Naval Postgraduate School they had lost most of their original water by evaporation. A portion of each one of these 50 samples was then oven dried and analyzed for salt content. Data for these samples are shown in Table II through Table V.

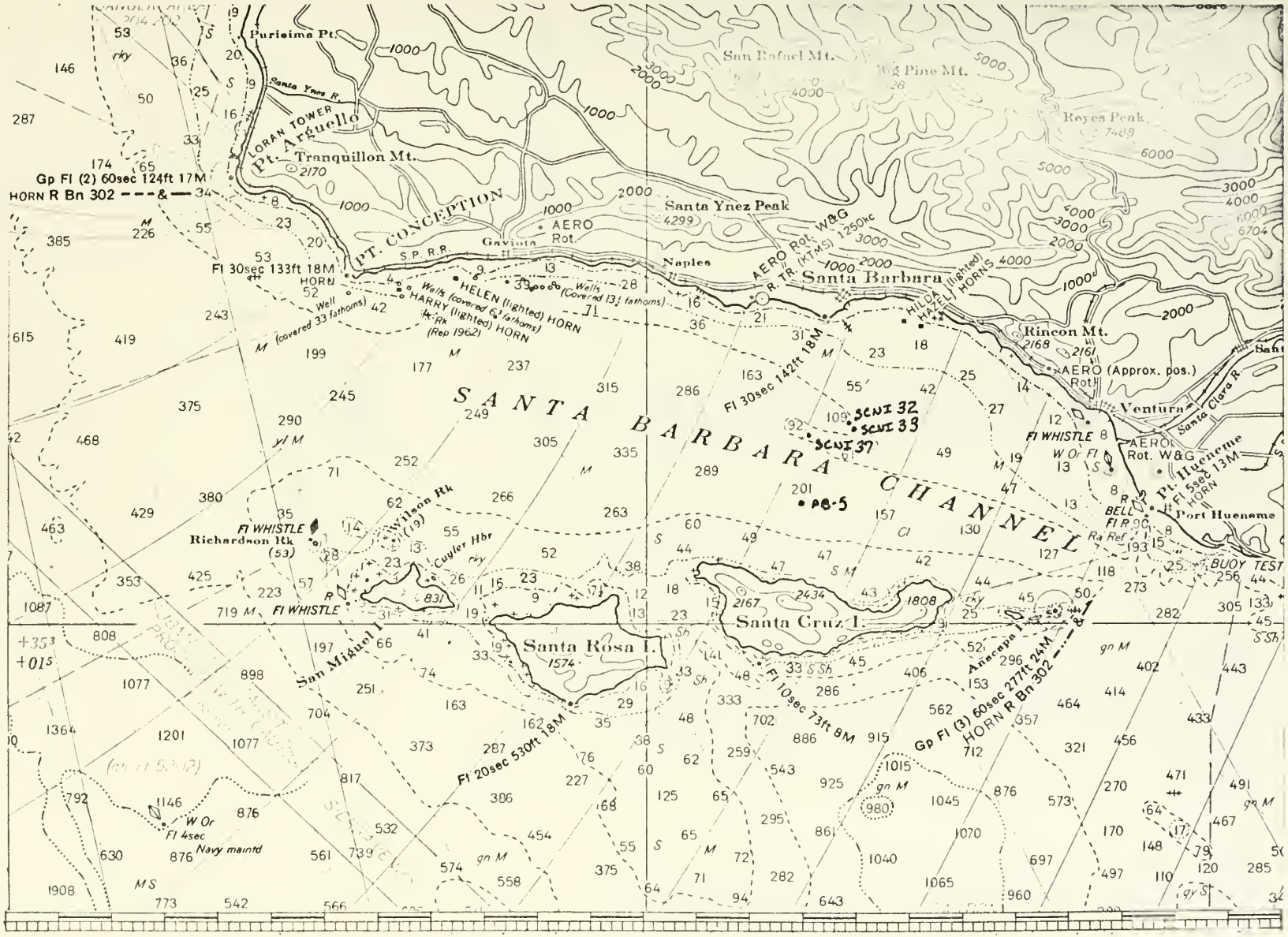

Figure 8. Santa Barbara Channel Core Locations

Depth in Core	Original Water Content	Computed Water Content	Error	Improved Water Content	Computed Salinity
3	187.2	202.0	7.9	182	36.7
6	148.0	169.0	14.2	144	38.9
9	141.4	164.0	16.0	136	39.4
12	131.7	168.0	26.8	136	43.3
15	136.2	172.0	26.3	137	42.9
18	119.3	154.0	29.1	129	43.8
21	113.9	148.0	29.9	115	44.3
24	108.5	130.0	20.8	110	40.7
27	110.3	142.0	27.8	107	43.7
30	100.1	132.0	31.9	100	44.8
33	99.2	129.0	30.0	97.4	44.2
36	97.3	131.0	34.7	98.2	45.8
39	96.4	115.0	19.3	85.7	40.6
42	93.7	133.0	41.9	98.5	48.2
45	92.8	130.0	40.1	96.0	49.0

Salinity of bottom water - 34 $^{o}/_{oo}$

Table II

Core PB-5

Depth in Core	Original Water Content	Computed Water Content	Error	Improved Water Content	Computed Salinity
3	75.6	84.7	12.1	76.6	38.2
6	66.0	79.1	19.9	67.3	40.8
9	55.9	63.2	13.0	52.3	38.4
12	47.6	63.4	33.3	51.3	45.3
15	44.8	50.4	12.5	40.2	38.2
18	48.9	63.4	29.7	49.8	44.1
21	49.4	58.8	19.0	45.8	40.5
24	40.3	49.4	22.6	38.0	41.5
27	39.7	50.9	28.2	38.9	43.6
30	40.1	49.9	24.4	37.8	42.5
33	40.5	51.3	26.7	38.7	43.1
36	39.2	50.6	29.1	37.9	43.9

Salinity of bottom water - 34 $^{o}/_{oo}$

Table III

Core SCNI 32

Depth in Core	Original Water Content	Computed Water Content	Error	Improved Water Content	Computed Salinity
3	95.7	102.5	7.1	92.6	36.4
6	83.3	97.3	15.7	82.9	39.8
9	65.3	72.4	10.9	59.7	38.8
12	50.8	65.2	27.6	52.7	43.6
15	51.3	65.2	27.1	51.8	43.2
18	50.5	67.7	34.1	52.7	45.6
21	48.9	61.0	24.2	47.5	42.4
24	35.6	42.1	17.8	33.1	40.2
27	38.6	45.2	17.1	34.5	39.8
30	39.2	49.3	26.6	37.4	42.8
33	38.6	49.9	29.3	37.3	43.9
36	43.1	55.5	28.8	41.6	43.7

Salinity of bottom water - 34 $^{o}/_{oo}$

Table IV

Core SCNI 33

Depth in Core	Original Water Content	Computed Water Content	Error	Improved Water Content	Computed Salinity
3	45.3	54.2	15.7	47.3	40.6
6	46.2	60.0	29.9	51.1	44.2
9	44.6	56.4	26.5	46.6	43.0
12	48.7	64.7	32.9	52.4	45.1
15	53.4	69.4	29.9	56.3	44.2
18		SAMPLES	MISSING		
21					
24	61.3	83.1	35.5	64.0	42.0
27	55.0	81.1	47.5	61.1	50.1
30	55.3	72.5	30.9	55.0	44.6
33	48.5	70.2	44.7	52.8	49.2
36	50.5	68.1	34.8	51.0	45.8
39	56.6	72.6	28.2	54.0	43.6

Salinity of bottom water - 34 $^{o}/oo$

Table V

Core SCNI 37

B. DISCUSSION OF RESULTS

1. General

It can be seen from Table I that under nearly ideal circumstances there is a very good correlation between the two methods of determining water content. In the case of the Monterey Bay samples the maximum error of the computed water content compared with the original was $\pm$ 1.5%.

The analysis of the Santa Barbara Channel cores indicated considerably larger deviations. Here the computed water contents ranged between seven and 47 percent greater than the corresponding original water content. When comparing the results of the two methods of determining water contents against depth in core (Figures 9 - 12) it appeared that the computed water contents varied in a very similar manner to that of the original water content, that is, when the original water content increased or decreased the computed value exhibited similar variations.

In an attempt to formulate this variation and obtain a method of predicting the error for these observations it was noted that there was some correlation between error and depth in core. The relative difference between the two methods was least at the top of the core and tended to increase with depth in core. When error was plotted versus the antilogarithm of depth in core, a generally linear relationship was observed. (Figure 13) Solving for error in terms of depth in core:

$$E = (.091 \ln^{-1} D + .009) \times 100 \qquad (14)$$

E = Error (%)

D = Depth in core (in.)

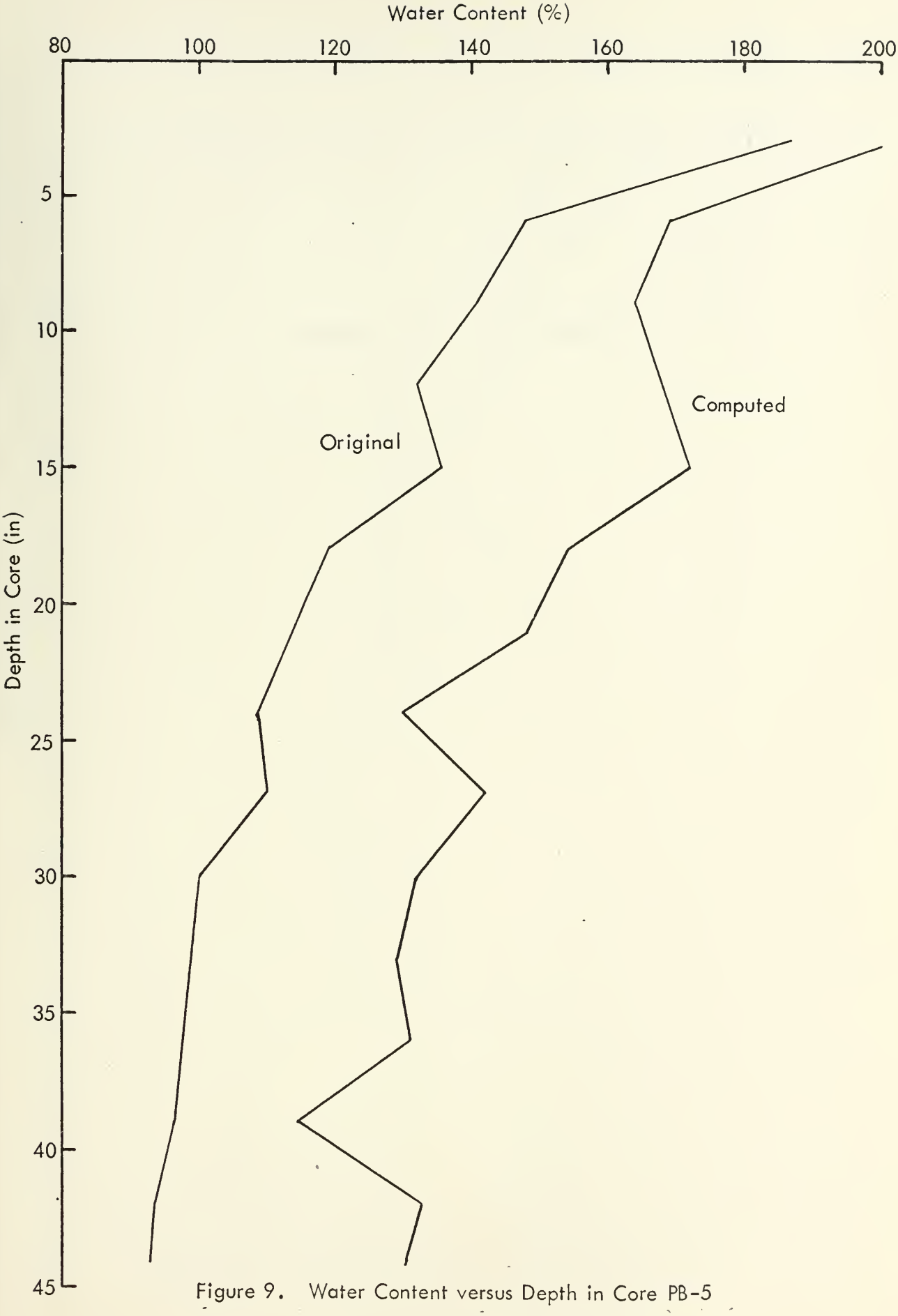

Figure 9. Water Content versus Depth in Core PB-5

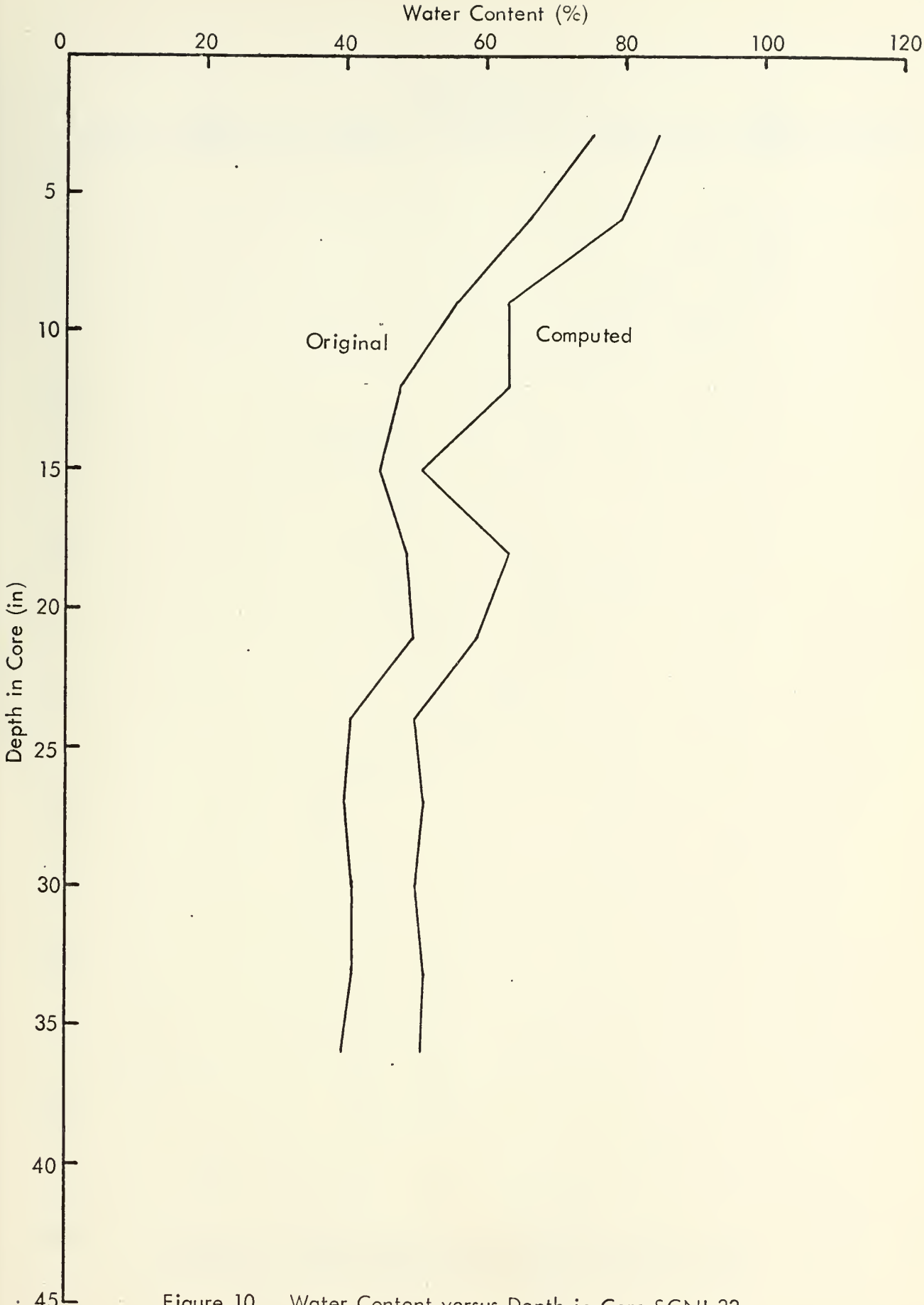

Figure 10. Water Content versus Depth in Core SCNI 32

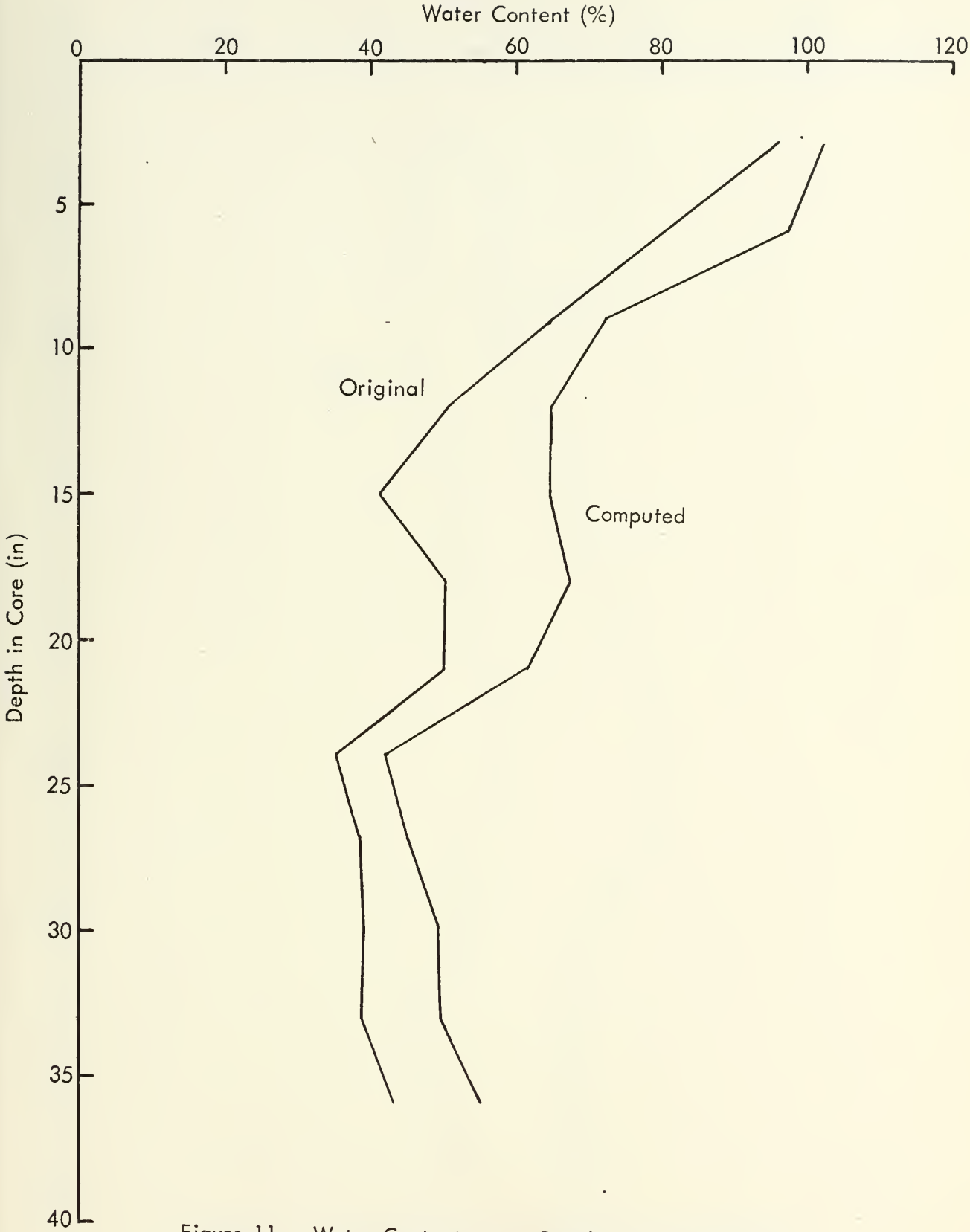

Figure 11. Water Content versus Depth in Core SCNI 33

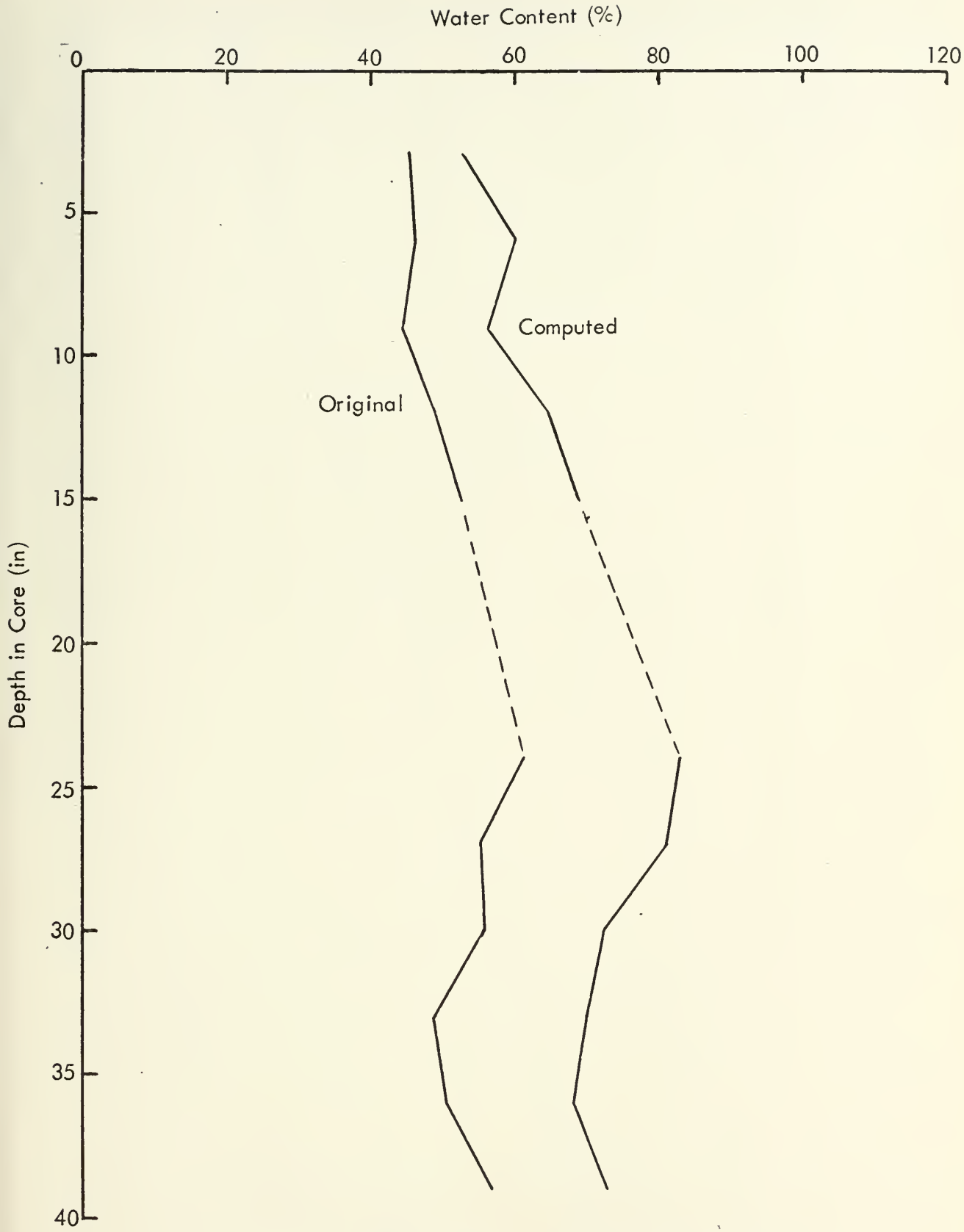

Figure 12. Water Content versus Depth in Core SCNI 37

Figure 13. Error versus $\ln^{-1}$ (depth in core)

From such a relationship the error can be predicted within $\pm$ 10% with a reliability of 90%. Applying equation (13) to the computed water content an improved approximation of the original water content could then be found by:

$$w_1 = \frac{w_c}{1 + \frac{E}{100}} = \frac{w_c}{.091 \ln^{-1} D + 1.009} \tag{15}$$

w_1 = Improved water content (%)

A comparison of the improved water contents with the original water contents is shown in Figure 14.

The above calculations assume that the salinity of the interstitial water remains constant with depth and is approximately equal to that of the sea water above it. Manheim (1970) reports that in central ocean sediments there exists a remarkable constancy in total salinity to the greatest depths and ages penetrated by the Deep Sea Drilling Project. Presley et. al. (1970) reports that in only two out of twenty-two samples from drilling on leg four of the JOIDES project did the chloride concentration differ from that of average sea water by as much as two per cent, and concluded that in slowly deposited pelagic clays and biogenic muds and oozes not only are chloride and bromide relatively inert to chemical changes occurring during diagenesis, but also concentration of pore water by ultrafiltration is not an important process.

The salinity of the pore waters are closest to that in the present open sea in the central parts of the oceans, but appear to become progressively more divergent as the continents and terrigenous

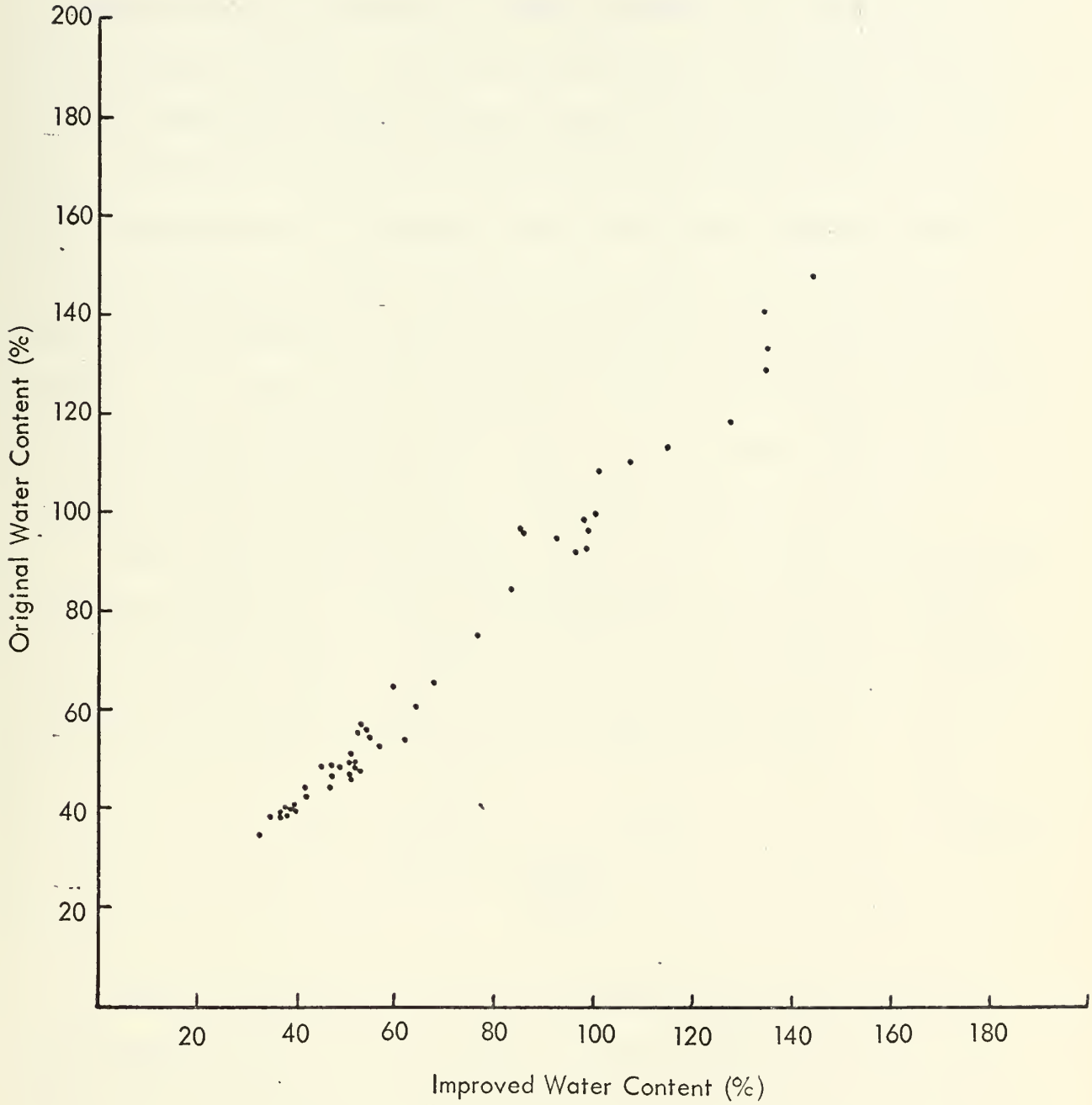

Figure 14. Improved Water Content versus Original Water Content

influences are approached. In the Gulf of Mexico there appears to be a sharp increase in salinity with depth possibly due to diffusion from underlying salt bodies. Off the coast of Florida a noticeable decrease in salt content with depth probably owing to fresh water seepage from the continent was observed. Extensions of land aquifers may cause this seepage as far as a hundred miles from shore. (Monney 1968) In beach sand the salinity of the pore water three feet below the surface was approximately the same as that of the water in the surf zone. (Oliff, et al. 1970) In this instance the movement of interstitial water is probably many times greater than in the deep ocean sediments and would therefore limit any conclusions that might be drawn.

If the salinity of the interstitial water does vary with depth in core in the Santa Barbara Channel, substituting the original water content for the computed water content in equation (10) and solving for original salinity, the resulting equation can be approximated by:

$$S_o = \frac{S_s W_A}{w_o W_s + \frac{S_s W_A}{100}} \times 100 \qquad (16)$$

A plot of this relationship versus depth (Figure 15-18) for each core suggests rather high salinities for the interstitial waters, but the range of variations is not greater than the equivalent variations of chlorinity with depth in core in coastal areas observed by Siever et. al. (1964). Siever offers as an explanation of this the possibility that either: (1) behavior of a compact clay as a semipermeable membrane concentrates salt in the sediment as fresher water of compaction is expressed, or (2) there was a trapping and preservation of unmodified

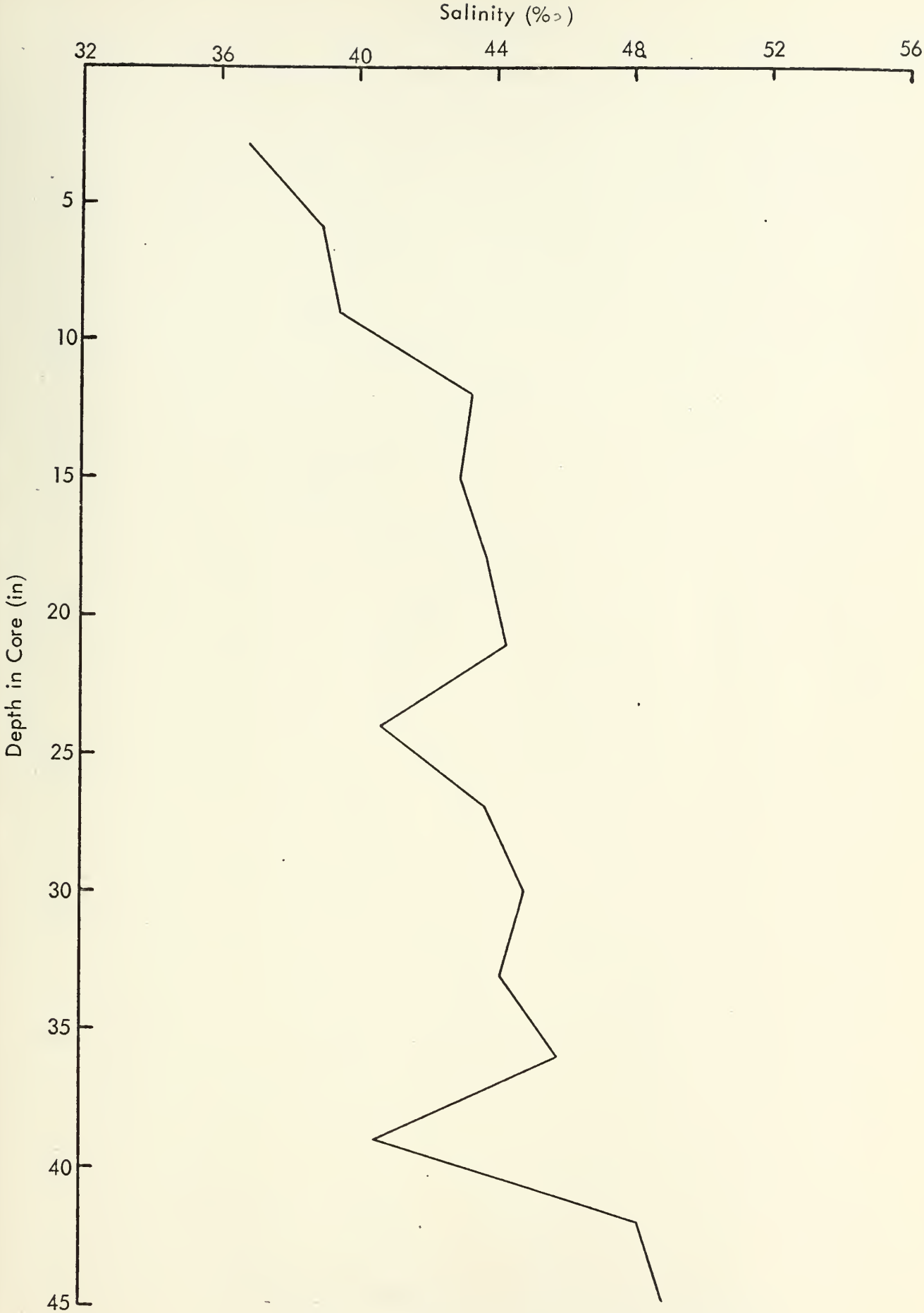

Figure 15. Salinity versus Depth in Core PB-5

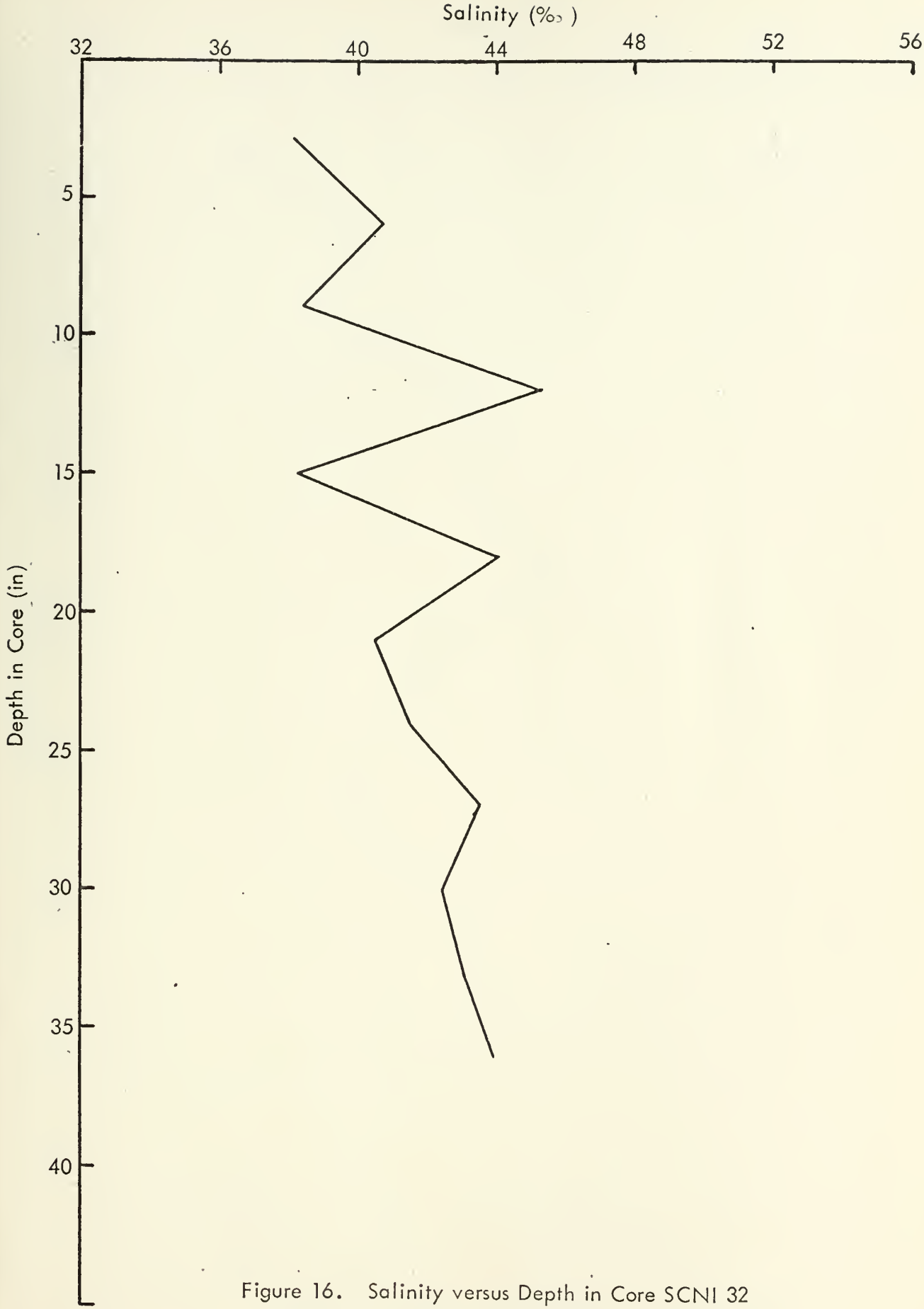

Figure 16. Salinity versus Depth in Core SCNI 32

Figure 17. Salinity versus Depth in Core SCNI 33

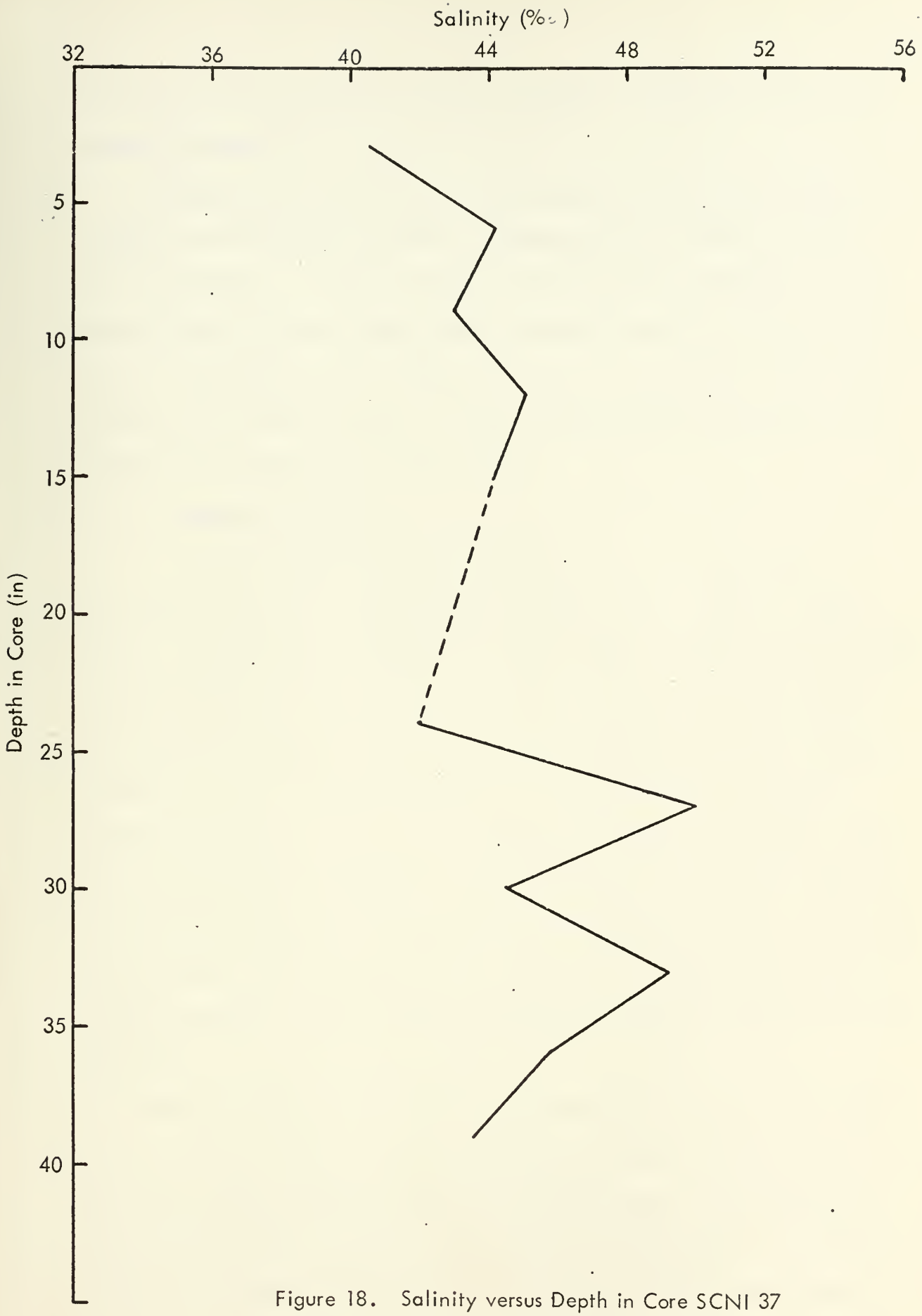

Figure 18. Salinity versus Depth in Core SCNI 37

sea water of the past when the 'paleosalinity' was different from the salinity of today.

The applicability of either of these explanations to the samples studied is questionable, and the resolution of this problem has not been attempted. A review of past work with marine sediments in the Santa Barbara channel offers little information on the reasons for the above. Regardless of the causal mechanism, the results of the tests on the NCEL cores indicate a probable variation of interstitial water salinity with depth in core in this area.

2. Sources of Error

If it were concluded that the conductivity cell method of determining the salt contents and ultimately water contents of sediments is valid, based on the fact that the method produced good results with the Monterey Bay samples, then there must be a explanation for the sources of errors observed in the results from the Santa Barbara Channel cores. As noted in the above, the salinity of interstitial waters in coastal areas is not necessarily constant with depth in core. It does not, however, appear that there would be sharp discontinuities between the salinity of the ocean bottom water and that of the interstitial water found in the top three inches of the core. This marked increase in the computed results could be attributed to several possible sources of error.

The first and most direct source would be an error resulting from the loss of fresh water due to evaporation during the period from when the cores were obtained to when the original water content analyses were made. As described earlier, the precautions taken in handling and storing appear adequate to render this type of fluid reduction very

light. Nevertheless, it is possible that there was some evaporation through the walls of the liners in which the cores were contained.

In a sample of marine sediment which is initially at 100 per cent saturation the evaporation processes should take place on or near the exposed surfaces of the sample. As the interstitial water evaporates it leaves behind an area of water with a higher salinity than at the interior of the sample. This imbalance of salinities tends to draw the lower salinity water from the center of the sample. In a rapid drying situation, such as in an oven, this migration would likely be minimized; however, in a more moderate environment such as air drying there would appear to be varying degrees of concentrations depending partially upon the rate of drying. The net effect would be that the residual salt would tend to be concentrated more towards the outer edges of the sample.

When samples of marine sediments are tested, normal tendency is to take the portion of a sample that has been least disturbed, and this is generally considered to be the center of the core. If such were the case with the Santa Barbara Channel cores and there did exist a slight amount of evaporation through the core liner prior to testing then there is a possibility that there would have been a greater amount of salt per unit weight in the outer remaining portion of the sample than in the part used for initial testing. This could lead to the high salinities observed in Figures 15-18. There could also have been effects of this process in the remaining samples as they air dried in their plastic containers. Only a small portion of these samples was needed for the chemical analysis for salt content and that portion was randomly taken with little consideration given to the possibility of salt concentration.

This may account for some of the larger deviations of the calculated salinities over the original ones.

In the analysis of these samples, they were diluted with distilled water to a salinity from 1/10 to 1/40 of that of the original interstitial water. To investigate the effect on dilution on the final salt content determinations, several samples were analyzed using from 100 to 300 grams of water. There was no significant variation caused by use of these different dilutions. There was also no indication that changing the length of time the solution was mechanically stirred resulted in variations in the end result. The inherent error of the conductivity measuring circuit is within $\pm$ 2% of the conductivity measured.

In summary, it is believed that the chief source of difference between the computed water content and the original water content results from some loss of water during the handling process and the necessity for making an assumption as to the salinity for the interstitial water in each sample. The computed water content would give more accurate results if the interstitial water salinity could be better known or could be more accurately predicted. As noted earlier, the salinity appears constant with depth in core in the deep ocean areas and therefore more accurate predictions are possible.

The errors introduced in the process of analysis of the sediments are comparatively small. By carefully selecting a representative portion of the sample to be tested, possible errors resulting from a concentration of salt in that sample would be minimized.

V. CONCLUSIONS

Several conclusions can be drawn from this study.

1. If the interstitial water salinity is known, water content determinations resulting from the analysis of salt contents in marine sediments are, for all practical purposes, as accurate as the generally used drying and weighing method.

2. Determination of water contents by the method developed in this investigation should be particularly applicable to deep ocean cores where the salinity of the interstitial water is constant with depth. For areas under land influences the conductivity cell method will give a good approximation of the original water content for the surface sediments where the salinity of the interstitial water is close to that of the ocean bottom water.

3. For cores with original water content data available. The conductivity cell approach will give a general indication as to the variation of salinity with depth in core and an indication of the amount of evaporation that has taken place prior to the evaluation of original water content.

APPENDIX A

***** CORE NO PB - 5 *****

LATITUDE 34 9.6 N LONGITUDE 119 45.5 W WATER DEPTH 200. FM

INTERVAL (IN)	0 - 3	3 - 6	6 - 9	9-12	12-15	15-18	18-21
BULK WET DENSITY (GM/CC)	1.280	1.374	1.343	1.412	1.411	1.452	1.462
VANE SHEAR STRENGTH (PSI)	.056	.080	.106	.210	.204	.233	.306
REMOLDED STRENGTH (PSI)	-	.024	.053	.054	.063	.115	.105
SENSITIVITY	-	3.3	2.0	3.9	3.3	2.0	2.9
ORIGINAL WATER CONTENT (P)	187.2	148.0	141.4	131.7	136.2	119.3	113.9
SPECIFIC GRAVITY OF SOLIDS	2.535	2.566	2.542	2.533	2.513	2.521	2.537
DRY DENSITY (GM/CC)	.446	.554	.556	.610	.597	.662	.683
VOID RATIO	4.687	3.632	3.570	3.155	3.208	2.808	2.712
POROSITY (P)	82.4	78.4	78.1	75.9	76.2	73.7	73.1
SATURATED VOID RATIO	4.747	3.799	3.594	3.335	3.424	3.008	2.890
LIQUID LIMIT (P)	108.1	-	-	-	105.1	-	-
PLASTIC LIMIT (P)	50.8	-	-	-	47.8	-	-
PLASTICITY INDEX	57.3	-	-	-	57.3	-	-
LIQUIDITY INDEX	238.	-	-	-	154.	-	-
COMPRESSION INDEX	.88	-	-	-	.86	-	-

***** CORE NO PB - 5 *****

LATITUDE 34 9.6 N LONGITUDE 119 45.5 W WATER DEPTH 200. FM

INTERVAL (IN)	21-24	24-27	27-30	30-33	33-36	36-39	39-42
BULK WET DENSITY (GM/CC)	1.464	1.478	1.491	1.498	1.501	1.493	1.519
VANE SHEAR STRENGTH (PSI)	.358	.388	.481	.663	.674	.671	.722
REMOLDED STRENGTH (PSI)	.179	.182	.206	.306	.340	.385	.205
SENSITIVITY	2.0	2.1	2.3	2.2	2.0	1.7	3.5
ORIGINAL WATER CONTENT (P)	108.5	110.3	100.1	99.2	97.3	96.4	93.7
SPECIFIC GRAVITY OF SOLIDS	2.597	2.588	2.592	2.626	2.582	2.588	2.572
DRY DENSITY (GM/CC)	.702	.702	.745	.752	.761	.760	.784
VOID RATIO	2.698	2.684	2.479	2.491	2.394	2.404	2.280
POROSITY (P)	73.0	72.9	71.3	71.4	70.5	70.6	69.5
SATURATED VOID RATIO	2.819	2.856	2.595	2.605	2.512	2.496	2.411
LIQUID LIMIT (P)	-	89.8	-	-	-	93.3	-
PLASTIC LIMIT (P)	-	44.9	-	-	-	71.0	-
PLASTICITY INDEX	-	44.9	-	-	-	22.3	-
LIQUIDITY INDEX	-	146.	-	-	-	114.	-
COMPRESSION INDEX	-	.72	-	-	-	.75	-

***** CORE NO PB - 5 *****

LATITUDE 34 9.6 N LONGITUDE 119 45.5 W WATER DEPTH 200. FM

INTERVAL (IN)	42-45
BULK WET DENSITY (GM/CC)	1.478
VANE SHEAR STRENGTH (PSI)	.348
REMOLDED STRENGTH (PSI)	.287
SENSITIVITY	1.2
ORIGINAL WATER CONTENT (P)	92.8
SPECIFIC GRAVITY OF SOLIDS	2.585
DRY DENSITY (GM/CC)	.767
VOID RATIO	2.370
POROSITY (P)	70.3
SATURATED VOID RATIO	2.398
LIQUID LIMIT (P)	-
PLASTIC LIMIT (P)	-
PLASTICITY INDEX	-
LIQUIDITY INDEX	-
COMPRESSION INDEX	-

***** CORE NO SCNI - 33 *****

LATITUDE 34 14.93 N LONGITUDE 119 40.58 W WATER DEPTH 101. FM

INTERVAL (IN)	0- 3	3- 6	6 - 9	9-12	12-15	15-18	18-21
COLOR (GSA NO.)	5Y3/2	5Y3/2	5Y3/2	5Y3/2	5Y3/2	5Y3/2	5Y3/2
ODOR	H2S	H2S	H2S	H2S	H2S	H2S	H2S
BULK WET DENSITY (PCF)	93.	97.	101.	108.	108.	108.	110.
VANE SHEAR STRENGTH (PSF)	21.	52.	58.	80.	95.	84.	80.
REMOLDED STRENGTH (PSF)	9.	19.	23.	27.	34.	32.	38.
SENSITIVITY	2.4	2.6	2.6	2.9	2.8	2.6	2.1
ORIGINAL WATER CONTENT (P)*	95.7	83.3	65.3	50.8	51.3	50.5	48.9
SPECIFIC GRAVITY OF SOLIDS	2.51	2.52	2.54	2.56	2.57	2.56	2.57
DRY DENSITY (PCF)	48.	53.	61.	72.	72.	72.	74.
VOID RATIO	2.29	1.98	1.59	1.23	1.24	1.22	1.16
POROSITY (P)	69.6	66.4	61.4	55.1	55.4	54.9	53.7
SATURATED VOID RATIO	2.40	2.10	1.66	1.30	1.32	1.29	1.26
LIQUID LIMIT (P)	62.	58.	49.	39.	39.	38.	36.
PLASTIC LIMIT (P)	32.	29.	28.	27.	27.	29.	28.
PLASTICITY INDEX	30.	29.	21.	12.	12.	9.	8.
LIQUIDITY INDEX	208.	187.	178.	206.	201.	240.	278.
COMPRESSION INDEX	.47	.43	.35	.26	.26	.25	.23
CARBONATE CARBON CONTENT (P)	.45	.61	.25	.28	.33	.31	.29
ORGANIC CARBON CONTENT (P)	1.56	1.52	1.27	1.02	.98	1.01	.90
SAND	13.0	17.0	18.8	31.0	27.8	35.8	36.8
SILT	45.8	43.5	49.5	46.8	46.6	42.5	40.8
CLAY	41.2	39.5	31.7	22.2	25.6	21.7	22.4
ACTIVITY	1.1	1.0	.9	.7	.6	.5	.5
MEDIAN DIAMETER (MM)	.0090	.0101	.0152	.0340	.0295	.0400	.0430
SEDIMENT TYPE	CLAYEY SILT	CLAYEY SILT	CLAYEY SILT	SAND SILT CLAY	SAND SILT CLAY	SAND SILT CLAY	SAND SILT CLAY

***** CORE NO SCNI - 33 *****

LATITUDE 34 14.93 N LONGITUDE 119 40.58 W WATER DEPTH 101. FM

INTERVAL (IN)	21-24	24-27	27-30	30-33	33-36
COLOR (GSA NO.)	5Y3/2	5Y3/2	5Y3/2	5Y3/2	5Y3/2
ODOR	H2S	H2S	H2S	H2S	H2S
BULK WET DENSITY (PCF)	117.	116.	116.	116.	113.
VANE SHEAR STRENGTH (PSF)	150.	107.	80.	81.	118.
REMOLDED STRENGTH (PSF)	61.	53.	64.	59.	59.
SENSITIVITY	2.5	2.0	1.2	1.4	2.0
ORIGINAL WATER CONTENT (P)*	35.6	38.6	39.2	38.6	43.1
SPECIFIC GRAVITY OF SOLIDS	2.60	2.58	2.58	2.58	2.59
DRY DENSITY (PCF)	86.	84.	83.	84.	79.
VOID RATIO	.88	.92	.94	.93	1.05
POROSITY (P)	46.8	47.8	48.4	48.2	51.3
SATURATED VOID RATIO	.93	1.00	1.01	1.00	1.12
LIQUID LIMIT (P)	30.	31.	33.	33.	36.
PLASTIC LIMIT (P)	99999.	99999.	29.	28.	28.
PLASTICITY INDEX	99999.	99999.	4.	5.	8.
LIQUIDITY INDEX	99999.	99999.	245.	209.	194.
COMPRESSION INDEX	.18	.19	.21	21	.23
CARBONATE CARBON CONTENT (P)	.47	.40	.32	.28	.24
ORGANIC CARBON CONTENT (P)	.59	.67	.75	.72	.84
SAND	45.0	46.0	36.5	43.5	31.0
SILT	40.3	40.0	45.2	37.5	45.8
CLAY	14.7	14.0	18.3	19.0	23.2
ACTIVITY	0.0	0.0	.3	.3	.5
MEDIAN DIAMETER (MM)	.0478	.0480	.0422	.0460	.0341
SEDIMENT TYPE	SILTY SAND	SILTY SAND	SILTY SAND	SILTY SAND	SAND SILT CLAY

***** CORE NO SCNI 32 *****

LATITUDE 34 14.85 N LONGITUDE 119 40.78 W WATER DEPTH 102. FM

INTERVAL (IN)	0-3	3-6	6-9	9-12	12-15	15-18	18-21
COLOR (GSA NO.)	5Y3/2	5Y3/2	5Y3/2	5Y3/2	5Y3/2	5Y3/2	5Y3/2
ODOR	H2S	H2S	H2S	H2S	H2S	H2S	H2S
BULK WET DENSITY (PCF)	95.	103.	107.	110.	112.	110.	109.
VANE SHEAR STRENGTH (PSF)	51.	47.	62.	92.	113.	105.	103.
REMOLDED STRENGTH (PSF)	16.	20.	31.	26.	32.	49.	54.
SENSITIVITY	3.2	2.4	2.0	3.5	3.6	2.1	1.9
ORIGINAL WATER CONTENT (P)*	75.6	66.0	55.9	47.6	44.8	48.9	49.4
SPECIFIC GRAVITY OF SOLIDS	2.52	2.52	2.54	2.55	2.56	2.55	2.56
DRY DENSITY (PCF)	54.	62.	68.	75.	78.	74.	73.
VOID RATIO	1.90	1.54	1.32	1.14	1.06	1.16	1.18
POROSITY (P)	65.6	60.6	56.8	53.3	51.5	53.7	54.2
SATURATED VOID RATIO	1.91	1.66	1.42	1.22	1.15	1.25	1.26
LIQUID LIMIT (P)	54.	47.	41.	35.	34.	38.	38.
PLASTIC LIMIT (P)	23.	30.	28.	29.	27.	30.	28.
PLASTICITY INDEX	31.	17.	13.	6.	7.	8.	10.
LIQUIDITY INDEX	172.	211.	207.	284.	270.	233.	229.
COMPRESSION INDEX	.39	.33	.28	.23	.22	.26	.25
CARBONATE CARBON CONTENT (P)	.59	.41	.27	.22	.25	.35	.44
ORGANIC CARBON CONTENT (P)	1.46	1.25	1.30	.90	.75	.95	.90
SAND	19.5	28.3	25.4	32.0	31.0	32.0	27.0
SILT	46.1	43.1	46.0	46.7	47.4	46.2	49.0
CLAY	34.4	28.6	28.6	21.3	21.6	21.8	24.0
ACTIVITY	1.3	.9	.7	.4	.4	.5	.6
MEDIAN DIAMETER	.0150	.0220	.0215	.0340	.0335	.0350	.0284
SEDIMENT TYPE	CLAYEY SILT	SAND SILT CLAY	SAND SILT CLAY	SAND SILT CLAY	SAND SILT CLAY	SAND SILT CLAY	SAND SILT CLAY

***** CORE NO SCNI - 32 *****

LATITUDE 34 14.85 N LONGITUDE 119 40.78 W WATER DEPTH 102. FM

INTERVAL (IN)	21-24	24-27	27-30	30-33	33-36
COLOR (GSA NO.)	5Y3/2	5Y3/2	5Y3/2	5Y3/2	5Y3/2
ODOR	H2S	H2S	H2S	H2S	H2S
BULK WET DENSITY (PCF)	116.	116.	116.	115.	117.
VANE SHEAR STRENGTH (PSF)	115.	155.	140.	145.	101.
REMOLDED STRENGTH (PSF)	62.	68.	74.	59.	72.
SENSITIVITY	1.9	2.3	1.9	2.5	1.4
ORIGINAL WATER CONTENT (P)*	40.3	39.7	40.1	40.5	39.2
SPECIFIC GRAVITY OF SOLIDS	2.57	2.55	2.57	2.57	2.56
DRY DENSITY (PCF)	82.	83.	83.	82.	84.
VOID RATIO	.95	.92	.94	.95	.90
POROSITY (P)	48.7	48.0	48.4	48.8	47.5
SATURATED VOID RATIO	1.04	1.01	1.03	1.04	1.00
LIQUID LIMIT (P)	32.	33.	32.	34.	33.
PLASTIC LIMIT (P)	99999.	30.	28.	29.	30.
PLASTICITY INDEX	99999.	3.	4.	5.	3.
LIQUIDITY INDEX	99999.	306.	301.	273.	338.
COMPRESSION INDEX	.20	.21	.20	.21	.20
CARBONATE CARBON CONTENT (P)	.23	.31	.40	.33	.44
ORGANIC CARBON CONTENT (P)	.79	.84	.75	.78	.75
SAND (P)	42.8	43.0	41.0	36.0	36.8
SILT (P)	40.5	42.2	42.8	44.5	45.0
CLAY (P)	16.7	14.8	16.2	19.5	18.2
ACTIVITY	0.0	.3	.3	.4	.2
MEDIAN DIAMETER (MM)	.0462	.0470	.0455	.0423	.0438
SEDIMENT TYPE	SILTY SAND	SILTY SAND	SILTY SAND	SILTY SAND	SILTY SAND

***** CORE NO SCNI - 37 *****

LATITUDE 34. 14.67 N LONGITUDE 119 44.52 W WATER DEPTH 100. FM

INTERVAL (IN)	0-3	3-6	6-9	9-12	12-15	15-18	18-21
COLOR (GSA NO.)	10Y4/2	10Y4/2	10Y4/2	10Y4/2	10Y4/2	10Y4/2	10Y4/2
ODOR	H2S	H2S	H2S	H2S	H2S	H2S	H2S
BULK WET DENSITY (PCF)	111.	111.	112.	109.	106.	104.	104.
VANE SHEAR STRENGTH (PSF)	46.	117.	139.	151.	100.	196.	211.
REMOLDED STRENGTH (PSF)	43.	57.	84.	96.	25.	71.	74.
SENSITIVITY	1.1	2.1	1.7	1.6	4.0	2.8	2.9
ORIGINAL WATER CONTENT (P)*	45.3	46.2	44.6	48.7	53.4	61.2	59.1
SPECIFIC GRAVITY OF SOLIDS	2.61	2.60	2.61	2.63	2.62	2.60	2.60
DRY DENSITY (PCF)	76.	76.	78.	73.	69.	64.	65.
VOID RATIO	1.14	1.14	1.10	1.25	1.36	1.53	1.48
POROSITY (P)	53.2	53.4	52.4	55.5	57.7	60.5	59.7
SATURATED VOID RATIO	1.18	1.20	1.17	1.28	1.40	1.59	1.53
LIQUID LIMIT (P)	33.	37.	38.	42.	43.	57.	56.
PLASTIC LIMIT (P)	99999.	29.	31.	26.	26.	33.	31.
PLASTICITY INDEX	99999.	8.	7.	16.	17.	24.	25.
LIQUIDITY INDEX	99999.	212.	191.	139.	156.	120.	112.
COMPRESSION INDEX	.21	.25	.25	.29	.30	.42	.41
CARBONATE CARBON CONTENT (CP)	.49	.58	.51	.71	.67	1.07	.92
ORGANIC CARBON CONTENT (P)	.84	.87	.92	.88	.90	0.91	1.05
SAND (P)	50.0	42.0	41.5	30.4	27.8	12.0	11.0
SILT (P)	33.8	38.2	38.2	45.4	45.1	48.8	50.6
CLAY (P)	16.2	19.8	20.3	24.2	27.1	39.2	38.4
ACTIVITY	9999.9	.5	.5	.9	.8	.8	.9
MEDIAN DIAMETER (MM)	.0500	.0458	.0440	.0305	.0265	.0100	.0094
SEDIMENT TYPE	SILTY SAND	SILTY SAND	SAND SILT CLAY	SAND SILT CLAY	SAND SILT CLAY	CLAYEY SILT	CLAYEY SILT

***** CORE NO SCNI - 37 *****

LATITUDE 34 14.67 N LONGITUDE 119 44.52 W WATER DEPTH 100. FM

INTERVAL (IN)	21-24	24-27	27-30	30-33	33-36	36-39
COLOR (GSA NO.)	10Y4/2	10Y4/2	10Y4/2	10Y4/2	10Y4/2	10Y4/2
ODOR	H2S	H2S	H2S	H2S	H2S	H2S
BULK WET DENSITY (PCF)	103.	105.	105.	108.	107.	103.
VANE SHEAR STRENGTH (PSF)	233.	249.	293.	226.	248.	201.
REMOLDED STRENGTH (PSF)	159.	100.	100.	87.	100.	81.
SENSITIVITY	1.5	2.5	2.9	2.6	2.5	2.5
ORIGINAL WATER CONTENT (P)*	61.3	55.0	55.3	48.5	50.5	56.6
SPECIFIC GRAVITY OF SOLIDS	2.62	2.59	2.63	2.62	2.65	2.64
DRY DENSITY (PCF)	64.	68.	68.	73.	71.	66.
VOID RATIO	1.55	1.38	1.43	1.25	1.33	1.51
POROSITY (P)	60.9	58.1	58.8	55.6	57.0	60.2
SATURATED VOID RATIO	1.60	1.43	1.45	1.27	1.34	1.49
LIQUID LIMIT (P)	60.	55.	55.	46.	49.	53.
PLASTIC LIMIT (P)	33.	31.	30.	30.	29.	30.
PLASTICITY INDEX	27.	24.	25.	16.	20.	23.
LIQUIDITY INDEX	106.	102.	100.	116.	106.	115.
COMPRESSION INDEX	.45	.40	.41	.32	.35	.39
CARBONATE CARBON CONTENT (P)	.80	.45	.76	.77	.83	.79
ORGANIC CARBON CONTENT (P)	1.00	1.30	.96	.74	.89	.98
SAND (P)	7.1	9.4	10.7	14.0	10.8	8.2
SILT (P)	49.4	50.4	50.7	54.6	56.1	51.8
CLAY (P)	43.5	40.2	38.6	31.4	33.1	40.0
ACTIVITY	.9	.8	.7	.7	.8	.8
MEDIAN DIAMETER (MM)	.0068	.0089	.0097	.0155	.0129	.0084
SEDIMENT TYPE	CLAYEY SILT	CLAYEY SILT	CLAYEY SILT	CLAYEY SILT	CLAYEY SILT	CLAYEY SILT

BIBLIOGRAPHY

1. Cole, R. H. and Coles, J. S., Physical Principles of Chemistry, W. H. Freeman and Company, San Francisco, 1964.

2. Daniels, F., Mathews, J. H., Williams, J. W., and Staff Experimental Physical Chemistry, McGraw-Hill Book Company, Inc., New York, 1949.

3. Defant, A., Physical Oceanography, Vol. I, Pergamon Press, London, 1961.

4. Emery, K. O., The Sea Off Southern California, A Modern Habitat of Petroleum, John Wiley and Sons, Inc., New York, 1960.

5. Handbook of Oceanographic Tables, SP-68, p. 319, U. S. Naval Oceanographic Office, Washington, 1966.

6. Hedberg, H. D., "Graivtational Compaction of Clays and Shales," American Journal of Science, v. 231, p. 241-287, 1936.

7. Hoag, R. W., Estimation of the Original Shear Strength of Deep Sea Sediments from Engineering Index Properties, M.S. Thesis, U. S. Naval Postgraduate School, Monterey, 1970.

8. Holmes, C. W., and Goodell, H. G., "The Prediction of Strength in the Sediments of St. Andrews Bay, Florida," Journal of Sedimentary Petrology, v. 34, No. I, p. 134-143, March 1964.

9. Hough, B. K., Basic Soils Engineering, The Ronald Press Company, New York, 1969.

10. King, J. D., The Drying of Marine Sediments for Water Content Determinations, M.S. Thesis, U. S. Naval Postgraduate School, Monterey, 1969.

11. Lambe, W. T., Soil Testing for Engineers, John Wiley and Sons, Inc., New York, 1951.

12. Malmberg, C. G.,"Electrical Conductivity of Dilute Solutions of'Sea Water' from 5 to 120° C," Journal of Research of the National Bureau of Standards, v. 69A, No. I, p. 39-43, January - February 1965.

13. Manheim, F. T., and Chan, K. M., "Interstitial Water Studies on Small Core Samples, Deep Sea Drilling Project, Leg 3," Initial Reports of the Deep Sea Drilling Project, v. 3, p. 663-666, 1970.

14. Monney, N. T., Engineering Evaluation of Marine Sediments, Proceedings of the 1968 Off-Shore Exploration Conference, New Orleans, 1968.

15. Morelock, J., "Shear Strength and Stability of Continental Slope Deposits, Western Gulf of Mexico," Journal of Geophysical Research, v. 74, No. 2, p. 465-482, 15 January 1969.

16. Nutting, P. G., "The Movement of Fluids in Porous Solids," Journal of Franklin Institute, No. 203, p. 313-324, 1927.

17. Oliff, W. D., Gardner, B. D., Turner, W. D., and Sharp, J. D., The Chemistry of Interstitial Water as a Measure of Conditions in a Sandy Beach, Water Research, v. 4, p. 179-188, Pergamon Press, London, 1970.

18. Presley, B. J., and Kaplan, I. R., Interstitial Water Chemistry: Deep Sea Drilling Project, Leg 4, Initial Reports of the Deep Sea Drilling Project, v. 4, p. 415-430, 1970.

19. Richards, A. F., Investigations of Deep Sea Sediment Cores, II Mass Physical Properties, U. S. Navy Hydrographic Office TR 106, October 1962.

20. Richards, A. F., and Keller, G. H., "Water Content Variability in a Silty Clay Core from off Nova Scotia," Limnology and Oceanography, v. 7, p. 426-427, 1962.

21. Siever, R., Beck, K. C., and Berner, R. A., "Composition of Interstitial Waters of Modern Sediments," Journal of Geology, v. 73, p. 39-73, 1965.

22. Strickland, J. D. H., and Parsons, T. R., A Manual of Sea Water Analysis, Fisheries Research Board of Canada, Ottawa, 1965.

23. Terzaghi, K., "Influence of Geological Factors on the Engineering Properties of Sediments," Economic Geology, 50th Anniversary Volume; Part II, p. 557-618, 1955.

24. Thomas, B. T., Thompson, T. G., and Utterback, C. L., "The Electrical Conductivity of Sea Water," International Council of the Exploration of the Sea, Journal du Conseil, v. 9, no. 1, 1934.

25. Trask, P. D., and Rolston, J. W., "Relation of Strength of Sediments to Water Content and Grain Size," Science, v. 111, p. 666-667, 1950.

26. Weast, R. C., ED., Handbook of Chemistry and Physics, 45 ed. The Chemical Rubber Co., Cleveland, 1964.

27. Weyl, P. K., "On the Change in Electrical Conductance of Sea Water with Temperature," Limnology and Oceanography, v. 9, p. 75-78, 1964.

28. Wooster, W. S., "Redefinition of Salinity," Mineralogy and Oceanography, p. 437-438, May 1969.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Professor R. J. Smith (Code 58Sj) Department of Oceanography Naval Postgraduate School Monterey, California 93940	3
4.	Department of Oceanography (Code 58) Naval Postgraduate School Monterey, California 93940	3
5.	Professor J. W. Schultz, (Code 5414) Naval Postgraduate School Monterey, California 93940	3
6.	Lieutenant John C. Peterson, USN Jones Cove South Bristol, Maine 04568	1
7.	Oceanographer of the Navy The Madison Building 732 North Washington Street Alexandria, Virginia 22314	1
8.	Commander Naval Facilities Engineering Command Code 03 Washington, D. C. 20390	10

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)

Naval Postgraduate School
Monterey, California 93940

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3. REPORT TITLE

Water Content Determinations For Dried Marine Sediments

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Master's Thesis; March 1971

5. AUTHOR(S) (First name, middle initial, last name)

John Christian Peterson

6. REPORT DATE

March 1971

7a. TOTAL NO. OF PAGES

66

7b. NO. OF REFS

28

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

Naval Postgraduate School
Monterey, California 93940

13. ABSTRACT

A quantitative analysis of residual salts in dried marine sediments was accomplished by reconstituting the sediment with distilled water and measuring the salinity of the resulting solution. The information obtained from these measurements provided an excellent basis for predicting the water content of the original unaltered samples. With the original salinity of the interstitial water known the water contents computed from the salt content determinations were, for all practical purposes, as accurate as the original water contents.

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6811

UNCLASSIFIED
Security Classification

A-31408

14 KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Computed Water Content						
Conductivity of Sea Water						
Conductivity Ratio						
Cores						
Dried Marine Sediments						
Engineering Properties of Marine Sediments						
Grain Diameter						
Salinity						
Sediment						
Shear Strength						
Water Content						

Thesis 126560
P414 Peterson
c.1 Water content determinations for dried marine sediments.

Thesis 126560
P414 Peterson
c.1 Water content determinations for dried marine sediments.

thesP414
Water content determinations for dried m
3 2768 001 97820 8
DUDLEY KNOX LIBRARY